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BULLETIN NO. 93

**SALINE WATER DEMINERALIZATION
AND NUCLEAR ENERGY IN THE
CALIFORNIA WATER PLAN**

EDMUND G. BROWN
Governor



HARVEY O. BANKS
Director of Water Resources

December, 1960

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Courtesy Fluor Corporation

Frontispiece

Model of the conceptual design of the one million gallon-per-day demonstration sea water conversion plant at San Diego.

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STATE OF CALIFORNIA
Department of Water Resources
SACRAMENTO

December 30, 1960

Honorable Edmund G. Brown, Governor
and Members of the Legislature of the
State of California

Gentlemen:

I have the honor to transmit herewith Bulletin No. 93 of the State Department of Water Resources, entitled "Saline Water Demineralization and Nuclear Energy in The California Water Plan".

The various processes used in producing fresh water from the oceans, and the present and predicted future costs for the most promising processes are described in this bulletin. The possible application of nuclear energy to sea water conversion and to the energy demand for pumping water supplies developed by the State Water Facilities are discussed.

Although no saline water demineralization technique yet developed can compete with the costs of large-scale development of natural sources of water in California, it is probable that saline water conversion plants will have a definite place in the water program. The Department of Water Resources will continue to take a definite and continuing interest in those areas of research and development that may have promise of eventually producing low cost converted water.

The study of the applications of nuclear energy to the various aspects of the problem of development of a practical and economic water program is of prime importance to the welfare of this State. The Department of Water Resources will maintain continued and detailed surveillance of developments in this field and their application to water development and distribution.

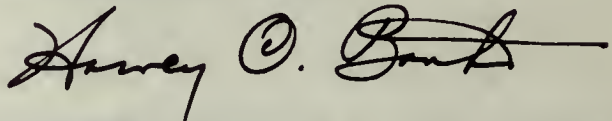
Honorable Edmund G. Brown
Governor, et al

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December 30, 1960

The information presented in the report should serve as an orientation to the complex problems of sea water conversion and the application of nuclear energy to California's water needs.

Very truly yours,

A handwritten signature in dark ink, appearing to read "Harvey O. Banks", with a long horizontal flourish extending to the right.

HARVEY O. BANKS
Director

ACKNOWLEDGMENT

The Department of Water Resources gratefully acknowledges the cooperation, valuable assistance, and technical data contributed by the following agencies and companies:

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Atomic Energy Commission

Special mention should be made of the helpful cooperation given by the sea water conversion research group headed by Professor E. D. Howe and the nuclear engineering research group under the direction of Professor L. M. Grossman, both at the University of California at Berkeley.

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CALIFORNIA LEGISLATIVE ACTIONS

The Subcommittee on Water Project Uses for Atomic Power of the Assembly Interim Committee on Conservation, Planning, and Public Works (Assemblyman Jack A. Beaver, Chairman), created by House Resolution No. 88, 1957, submitted a partial report to the 1958 Session of the Legislature. The subcommittee at the time recommended that:

"1. The Department of Water Resources give added impetus to its program of evaluation and study of nuclear energy in relation to the pump lift requirements of the Feather River Project.

"2. The Department of Water Resources give full consideration to the implications for California of the saline water conversion legislation before the Congress and be prepared to recommend an appropriate course of action in this regard to the 1959 Session of the Legislature.

"3. The University of California, with due regard for its educational and basic research responsibilities, attempt to concentrate its efforts in nuclear and saline water conversion research into channels most likely to be of practical use to the State as a whole.

"4. The Legislature support reasonable augmentations to the programs of the Department of Water Resources and the University in these fields.

"5. The Committee should continue to actively monitor the existing state programs in these fields and continue its study of the best procedures to be followed by the State in its approach to these problems."

Created by House Resolution No. 234, 1957, the Subcommittee on Water Project Power of the Assembly Interim Committee on Conservation, Planning, and Public Works (Assemblyman Jack A. Beaver, Chairman), carried on the work initiated by the predecessor committee and submitted its final report (Volume 13, Number 27 of Assembly Interim Committee Reports 1957-59). In that report, the committee recommended:

"1. Continued legislative support for the programs of the Department of Water Resources and the University of California in the fields of saline water conversion and nuclear energy sources for water projects.

"2. Immediate financial participation by the State in a joint federal-state program for the construction and operation of a demonstration plant for the conversion of sea water on the California coast.

"3. Intensified effort on the part of the Department of Water Resources and the University of California to provide technological solutions to the problems posed by the potential energy crisis.

"4. Continuation of a legislative committee as a source of information and of coordination of the various aspects of the problems."

In support of the foregoing recommendations, the Legislature appropriated funds to the Department of Water Resources for investigations of saline water conversion and potential uses of nuclear power sources as follows:

<u>Fiscal year</u>	<u>Capital outlay</u>	<u>Studies and investigations</u>
1958-1959		\$117,680
1959-1960	1,600,000 ^{1/}	98,551
1960-1961		217,412

Appropriations to the University of California for research in saline water conversion have been as follows:

Fiscal years 1952 through 1958	\$431,000
Fiscal year 1959	420,900
Fiscal year 1960	420,900

^{1/} For a cooperative federal-state sea water conversion demonstration plant: (a) Engineering studies \$100,000; (b) Investigation, planning, and constructing conversion plant \$1,500,000.

SYNOPSIS

This bulletin describes the various phases of the State's interest in nuclear energy and water demineralization as initiated through the work of two legislative subcommittees created by House Resolutions No. 88 and No. 234 in 1957. The Department of Water Resources commenced a long-range program in the fall of 1957 for the study and evaluation of the problems of nuclear energy and saline water conversion, as they apply to the water problems of California.

The history, the principal demineralization techniques, the present and probable future water costs, and research and development programs, both federal and state, are described and discussed.

The conversion of saline water has been proved to be technically feasible, through the successful development of a number of processes. The greatest obstacle to its more widespread application today is its relatively high cost and much effort is being directed toward reducing costs. It is anticipated that most reductions will be brought about by gradual improvements in efficiency, more effective scale and corrosion control, better heat transfer, and cheaper materials and fabrication techniques. Also a breakthrough to lower costs may occur, perhaps as the result of a process not yet known or envisioned. However, conversion of sea and brackish water in the foreseeable future will not be able to compete in cost with large-scale development of the State's natural water resources. The costs of sea water conversion alone, excluding transportation to places of use, are estimated to

lie in the range of two to five times the currently estimated costs of water supplies made available by the State Water Facilities.

The present status and future possibilities of nuclear energy applications are reviewed and discussed and the principles of fission and fusion reactions are described. It is indicated that electrical and mechanical power produced by nuclear devices will, within the coming 10 to 15 years, become economically competitive with power produced by hydroelectric and fossil fuel generating plants. Therefore, it may be expected that nuclear energy will have a marked effect on the future development of the California Water Plan, especially for electrical and mechanical power for pumping.

The types and possible uses of so-called "nonconventional" sources of energy are reviewed and discussed. It is not anticipated, however, that such sources of energy will have an important immediate influence on the current program for large-scale development of the State's water resources.

The future program of the State in the development of water demineralization and nuclear energy applications is discussed. It is concluded that, although present water demineralization techniques are not yet competitive with the economies achieved in the large-scale development of natural water resources in California, it is probable that saline water conversion plants may have a definite place in the future water program. The Department of Water Resources has a definite and continuing interest in those aspects of research and development that give promise of producing fresh water

supplies at reasonable cost. The Department of Water Resources is also increasingly involved in the study of the applications of nuclear energy to the development of a practical and economical water program.

GLOSSARY

Algae. A large group of simple organisms, most aquatic. They contain chlorophyll and/or other pigments capable of storing and utilizing energy from sunlight.

Alpha Particle. The nucleus of the helium atom of mass number 4. It has a positive charge.

Anion. A negative charged ion.

Anode. Positive electrode.

Atomic Number. The number of electrons in an atom, determining the chemical properties of the atom.

Beta Particle. High-speed electrons that are emitted during the disintegration process of certain radioactive materials.

Btu. British thermal unit - the amount of heat required to raise the temperature of one pound of water 1° F.

Calorie. The unit quantity of heat in metric units - the heat required to raise the temperature of one gram of water 1° C.

Catalyst. A substance which by its presence alters the rate of a reaction and itself remains unchanged at the end of the reaction.

Cathode. Negative electrode.

Cation. A positively charged ion.

Curie. The quantity of a radioactive substance having a radiation capacity equal to that of one gram of radium.

Deuterium. Heavy hydrogen, an isotope of hydrogen having atomic mass 2.

Effect. For the purposes of this report an effect is the compartment or vessel in which the sea water is brought to boiling by the addition of heat from either the condensing fresh water in submerged coils or from steam heating coils. Several effects connected in series is termed multiple-effect.

Electron. A negatively charged constituent of the atom, having a mass of about 9.1×10^{-28} gram, that is, about 1/1840 that of a hydrogen atom. The electrons surrounding the nucleus of an atom determine its chemical properties. An electric current is a stream of electrons.

Electron Volt (ev). The unit energy used in nuclear physics.
The energy acquired by an electron when accelerated through a potential of one volt: $= 1.52 \times 10^{-16}$ Btu.

Fossil Fuel. A general name for those fuels (for example, coal and oil) formed underground in the geological past.

Fuel Cell. A source of energy by oxidation by electro-chemical means at more or less ordinary temperatures, as opposed to combustion.

Gamma Rays. A product of radioactive disintegration: highly penetrating electromagnetic waves of similar nature to x-rays, but of shorter wavelength.

Heavy Hydrogen. See Deuterium.

Heavy Water. Deuterium oxide. Its chemical properties are nearly the same as those of normal water, but it is about 10 percent denser and has slightly higher melting and boiling points. It constitutes about one part in 6,000 of ordinary water.

Ion. An atom or group of atoms electrically charged by the loss or gain of one or more electrons. Its migration through an electrolyte or a gas constitutes the transport of electricity. Each ion carries one or more electric charges equal to its chemical valence.

Isotope. A variety of an element which has the same number of electrons and therefore the same chemical properties, but a different mass.

Kilowatt. The usual unit of electrical power, being equal to 1,000 watts. A common size electric light bulb consumes 100 watts or 1/10 kilowatt.

Kilowatt-hour. The usual unit of electrical energy. It is the amount of energy consumed when one kilowatt is used for one hour.

Mass Number. The number of protons and neutrons in the nucleus of an atom, accounting for almost the whole of the mass of the atom.

Mev. One million ev.

mw. Megawatt, one million watts.

Mill. One tenth of a cent.

Nucleus. The core of an atom about which the electrons revolve. It is comprised of protons and neutrons and has a positive charge equal to the number of protons.

Neutron. A constituent of the atomic nucleus having the same mass as a proton, but no electric charge.

Proton. A constituent of the atomic nucleus having a positive charge equal to that of an electron, but about 1,840 times greater mass.

Semi-conductor. A material intermediate between metals and non-metals, and capable of passing an electric current under certain conditions.

Stage. For the purposes of this report, a stage is a compartment or vessel in which the sea water is evaporated and the fresh water is condensed in the same compartment. Several stages connected in series is termed multistage.

Tritium. An isotope of hydrogen having atomic mass 3.

CHAPTER I. DEVELOPMENT OF STATE INTEREST IN WATER DEMINERALIZATION AND NUCLEAR ENERGY

Preface

Within the past several decades, thoughtful individuals and groups throughout the world have been deeply concerned with means of meeting, in arid and semiarid regions, the ever-increasing demands for fresh water for municipalities, irrigation, and industry. The feasibility of converting sea and brackish water has, as a consequence, been receiving more and more attention as a possible medium for meeting these increasing demands. In the United States development of economical conversion processes is being vigorously pursued by federal and state agencies and by private groups. Abroad, methods of conversion are being studied in at least 15 countries -- in Europe under the sponsorship of the Organization of European Cooperation, and in other regions of the world, largely under the encouragement of United Nations Educational, Scientific, and Cultural Organization (UNESCO), and by individual governments and private interests.

This bulletin outlines the history and present status of saline water conversion and describes the activities of the Department of Water Resources in this field and also in the field of nuclear and other nonconventional power sources required for demineralization processes and for pumping of large volumes of water. Other applications of nuclear phenomena, such as radioisotopes and the possible use of nuclear explosives, are also described.

History

Both the California Legislature and the Department of Water Resources have, for a number of years, fully realized the implications to the interests of the State in the fields of water demineralization and in the application of nuclear energy to the solution of water problems. The Legislature has been active in this field, and the Subcommittee on Water and Power of the Assembly Committee on Conservation, Planning, and Public Works, under the chairmanship of Assemblyman Jack A. Beaver, has conducted many policy studies on these subjects.

The department has instituted a continuing program of cooperative activity with the University of California, the Federal Government, and other organizations, for the investigation and study of promising lines of research and development in the fields of saline water conversion and nuclear energy. The department is also engaged in an appraisal of the possible impact of scientific advances on the future planning of the State's water development program. Both the department and the University of California, under a directive of the Legislature and by its appropriation of funds, have expanded and expedited studies, and research and development activities in these fields.

In 1958, the department consummated cooperative agreements with the University of California and with the Federal Office of Saline Water. Both agreements have operated to the considerable mutual benefit of the scientific-technical programs.

With regard to the department's cooperative agreement with the University of California, the role of the University is to give major attention to the less well-developed methods of saline water conversion, conducting theoretical and laboratory research and experimentation with small pilot plants where deemed desirable. The department, on the other hand, may carry certain seemingly promising processes into the engineering development stage when and if conditions warrant.

Objectives and Activities

The objectives and corresponding activities of the Department of Water Resources are dual in nature. They are being directed to the determination of (1) feasible and economical developments in saline water conversion processes, and (2) the means by which applications of nuclear and other more nonconventional sources of power may be employed in the form of heat or electricity to supply the energy needed to create additional supplies of fresh water by demineralization from ocean or brackish water sources, or as pumping power in the conveyance of large quantities of natural fresh waters.

To successfully accomplish the above objectives with minimum cost and time, mutual awareness of the problems between the scientist and engineer, and the citizens in general are required, as is close, continuous, coordinated efforts of both groups. This is a trend that has been increasingly employed with success in other complex technological fields by both the Federal Government and private industry during the past half century.

Up to the present time, the activities of the department in saline water conversion have been six-fold, viz.:

1. To acquire all possible knowledge concerning existing and potential processes.
2. To associate and cooperate with public and private agencies conducting research and development.
3. To collect and analyze technical and cost data concerning conversion plants now in operation or to be constructed.
4. To investigate nuclear energy and other power sources such as solar, wind, tidal, geothermal, waste industrial heat and the latent thermal energy of the sea.
5. To investigate and plan in specific areas for the application of sea and brackish water demineralization plants and nuclear energy for pumping purposes.
6. To cooperate with the Federal Government in design and construction of a demonstration sea water conversion plant at San Diego.

Objectives for the immediate future include assistance in the construction of the San Diego demonstration sea water conversion plant, continuation of engineering studies on one or more promising conversion processes, a study on the application of nuclear power to pumping in the California Aqueduct System, and investigation of additional applications of radioisotopes in department operations.

An example of a specific task planned for the future is that of developing reliable means of predicting, from the results of laboratory, pilot plant, or existing water demineralization plant observations, the operating characteristics, design data, and related capital and operating costs of large full-scale saline water conversion plants.

Possible Future Effect on
the California Water Plan

The present status of saline water conversion and its future possibilities indicate that, with the exception of the possibility of a major technological breakthrough, the conversion of sea and brackish water in California will cost at least two to five times more than large-scale development and transportation of natural water sources. However, small-scale uses of saline water conversion may find practical and economic justification in some areas of the State isolated from developed natural water facilities.

In the study of nuclear energy applications, it is indicated that electrical and mechanical power produced by nuclear devices will, within the next 10 to 15 years, become economically competitive with power produced by hydroelectric and fossil fuel generating plants. Therefore, it may be expected that nuclear energy will have a marked effect on the future development of the California Water Plan, especially for the electrical energy requirements for pumping.

The forms and possible uses of so-called "nonconventional sources of energy"^{1/} indicate that useful application to water development is unlikely. It is not expected that the uses of these unusual sources of energy can have either an unexpected or an important influence on the course of large-scale development of the State's water resources.

^{1/} Energy derived from sources other than fossil fuels or nuclear energy.

CHAPTER II. SALINE WATER DEMINERALIZATION

Introduction

The rapid growth of population and the parallel intensive industrialization and urbanization, creating an increasing need for agricultural products in California and in other areas of the world, have generated a very active interest in the possibilities of economically demineralizing^{1/} sea and brackish water.

Nature, in the fresh water recovery phase of the hydrologic cycle, relies on solar energy to evaporate enormous quantities of water from the oceans and inland seas. Unfortunately, however, due to maldistribution of natural precipitation and, in some places due to heavy population and related urban and industrial development, many areas of the globe are deficient or are rapidly becoming deficient in fresh water supplies. Such is the case in the semiarid and arid regions of Central and Southern California.

Historical Background

The conversion of saline water into water potable to man and useful to agriculture and industry is not new, and a number of methods of accomplishing conversion have been developed. Of the several methods, distillation is the oldest and is likely the result of man's imitation of nature's own conversion process as represented by the hydrologic cycle.

^{1/} In this bulletin, "demineralization" and "conversion" are used interchangeably.

In this cycle, radiant energy from the sun in the form of heat evaporates pure water from the surface of the salty oceans. Subsequent meteorological processes cause the condensation and precipitation of atmospheric moisture onto the surface of the land, followed by seepage of the water into the ground or conveyance by streams and rivers into reservoirs, lakes, or oceans.

Crude distillation techniques for the purification of chemicals probably antedate written history. However, specific applications to the production of pure water, for pharmaceutical purposes, appear to have come at a much later time. In 1683, an English patent was issued to a man named Fitzgerald for a method of "sweetening" sea water. Thereafter, occasional references to distillation of sea water appear in the literature, until the advent of the steamship in the nineteenth century when distillation on shipboard became fairly common.

The earliest and largest distillation plant especially designed to produce potable water from brackish supplies was constructed in the high Atacama Desert of Northern Chile, at Las Salinas, in 1872. Extensive silver mining operations were then in progress and all fresh water, prior to that time, had to be hauled great distances. The Las Salinas plant was a glass covered solar still encompassing an area of about 1.25 acres. It produced a maximum of 5,000 gallons of fresh water per day. On the basis of prices prevalent in those days the total capital cost including the distiller, windmills, pumps, piping, and tanks was reported to be \$55,000. This plant was in continuous operation for a period of 30 years.

The use of distilled water on steamships, produced by condensing steam from the vessel's boilers, also dates back to the 1880's and this method has been increasingly employed at sea during the present century to produce drinking and boiler make-up water. Distillation equipment on ships has eliminated the necessity of conveying fresh water between ports, and has resulted in increased cargo space. All large modern ships are equipped with fresh water distillation equipment.

Land based sea water conversion plants in operation or under construction throughout the world now have a total fresh water production capability of about 24 million gallons per day, or roughly equivalent to the fresh water demands of an average California city having a population of about 160,000. A decade ago, the total installed capacity was less than two million gallons per day, which consisted principally of the plants located in Curacao and Aruba. Processes other than distillation were studied during this early period, but little practical application resulted.

The first plants constructed in the West Indies, at Aruba and Curacao, were to provide water for domestic use. Precipitation in these two islands is limited in quantity and occurs only during a short annual rainfall period. The topography is such that little of the runoff is retained on the surface and the available ground water supplies are scant. The only alternative source of fresh water was that imported by tankers operating from South American ports.

During World War II, portable water distilling units, both for purifying the sea water and for the purification of brackish inland waters, were vitally needed by the armed services. This need was largely met by the use of the Kleinschmidt type of vapor compression distillation unit, which was produced in relatively large numbers. These units, unfortunately, had small capacities and they produced water at extremely high cost. However, they were both compact and versatile. Since 1945, the same principle has been applied at remote armed forces bases where no fresh water is obtainable except by expensive sea transport. Examples of such locations are Greenland in the North Atlantic, Wake Island in the Pacific, and Turks Island in the Bahamas. More recently this type of unit has been installed on some off-shore oil drilling platforms (Texas towers).

Several years ago, when the Sheikdom of Kuwait, on the Arabian Gulf, undertook the development of extensive oil fields there arose a need for large supplies of fresh water. To supply this need, distilling plants with an installed capability in excess of 6.5 million gallons per day have been constructed. The selection of the type of plant constructed was influenced by the availability of relatively inexpensive oil as a fuel.

As another example, in 1955 the government of Aruba, Netherlands West Indies, was faced with the problem of a growing population and increased water and power needs. A comprehensive economic and engineering survey was made of all known techniques of sea water conversion. After consideration of the

various alternatives, a combined sea water conversion and electric generating plant was selected. With this combination, fresh water and power could be produced from the one plant with higher economy than with two separate plants.

Present Status of Activity in Saline Water Conversion

In the years since World War II, the number of large land based saline water conversion plants has been on the increase. The largest plants were constructed in arid areas where fresh water was scarce and fuel was plentiful. As more experience was gained in saline water conversion, technical advances made possible the reduction in cost of converted water. Many countries began to actively engage in saline water conversion research programs with hopes of solving their water shortage problems. In order to facilitate the exchange of information among countries and among workers in the field, the United Nations Educational, Scientific, and Cultural Organization (UNESCO) conducted a number of conferences, as did professional and governmental agencies, particularly in the United States.

Conversion Plants Now in Operation

The number of land based saline water conversion installations in operations is growing rapidly. For example, plants recently have been ordered or completed in such widely separated areas as Ecuador, Bermuda, St. John, Virgin Islands, Kuwait, Aruba, Curacao, and Peru. Table 1 indicates the major sea and brackish water conversion plants located throughout the world.

TABLE 1

MAJOR SEA AND BRACKISH WATER CONVERSION PLANTS^{1/}

(Existing or under construction)

Location	: Nature of : : water de- : : mineralized:	Process	: Approximate installed : capacity (gallons per : day of fresh water)
Kuwait (Arabian Gulf)	Sea ^{2/}	Distillation	6,750,000
Aruba (Netherlands Antilles)	Sea	Distillation	3,500,000
Curacao (Netherlands Antilles)	Sea	Distillation	3,000,000
Union of South Africa	Brackish	Electrodialysis	2,800,000
Nassau, Bahamas	Sea	Distillation	1,200,000
Cordon, Venezuela	Sea	Distillation	1,200,000
Eniwetoc	Sea	Distillation	650,000
Qatar	Sea	Distillation	600,000
Isle of Guernsey	Sea	Distillation	550,000
Las Piedras, Venezuela	Sea	Distillation	450,000
Mirafiori, Italy	Sea	Distillation	300,000
Marcus Hook, Pennsylvania	Brackish	Distillation	300,000
Iran (Iranian Oil Co.)	Sea	Distillation	300,000
Virgin Islands	Sea	Distillation	275,000
Kindley AFB, Bermuda	Sea	Distillation	225,000
Dharan AFB, Arabia	Sea	Distillation	200,000
Gibraltar	Sea	Distillation	200,000

TABLE 1 (continued)

MAJOR SEA AND BRACKISH WATER CONVERSION PLANTS^{1/}

(Existing or under construction)

Location	: Nature of : : water de- : : mineralized:	Process	: Approximate installed : capacity (gallons per : day of fresh water)
Government of Ecuador	Sea	Distillation	200,000
Morro Bay, Cali- fornia (PG&E)	Sea	Distillation	150,000
Thule AFB, Greenland	Sea	Distillation	130,000
Gulf of Mexico (Freeport Sul- fur Company)	Sea	Distillation	120,000
Ventura, Cali- fornia (So. Cal. Edison Co.)	Sea	Distillation	100,000
Tobruk, Libya	Brackish	Electrodialysis	100,000
Texas	Brackish	Electrodialysis	86,400
Bahrein Island	Brackish	Electrodialysis	86,400
Hanna City, Illinois	Brackish	Electrodialysis	70,000
Havre, Montana	Brackish	Electrodialysis	56,000
Gettysberg, South Dakota	Brackish	Electrodialysis	40,000
Winslow, Arizona	Brackish	Electrodialysis	35,000
Coalinga, California	Brackish	Electrodialysis	28,000
Netherlands	Sea	Electrodialysis	16,000
Kuwait (Arab State)	Brackish	Electrodialysis	16,000
Southern Algeria	Brackish	Electrodialysis	15,000

TABLE 1 (continued)

MAJOR SEA AND BRACKISH WATER CONVERSION PLANTS^{1/}

(Existing or under construction)

Location	: Nature of : : water de- : : mineralized:	Process	:Approximate installed :capacity (gallons per : day of fresh water)
Saltair, Utah	Brackish	Electrodialysis	12,000
New York (Thru- way Authority)	Brackish	Electrodialysis	12,000

1/ Excludes numerous installations on naval and commercial ships and portable units used in remote Pacific Islands and in other parts of the world.

2/ Salinity of Arabian Gulf waters averages 43,000 ppm compared with 35,000 ppm for "standard" sea water.

In addition to the plants specifically constructed for the purpose of converting highly saline waters, many companies are engaged in the production of bottled drinking water, using similar processes, and produce a moderate amount of distilled water from ordinary potable water which may contain several hundred parts per million of dissolved solids. Plants with capacities as great as 100,000 gallons per day have been constructed in Southern California. The water produced is sold both commercially and domestically to those who, for one reason or another, desire to have distilled water available. Such treatment is not required for domestic uses in California except as personal preference dictates, for the quality of normal municipal supplies utilized as source water is within the standards permitted for such uses.

Institutions Engaged in Research on Saline Water Conversion

The General Conference of United Nations Educational, Scientific, and Cultural Organization (UNESCO), at its ninth session in December 1956, included in the Major Project on Scientific Research on Arid Lands a proposal to establish a central service to facilitate the exchange of information between the various institutions working on saline water conversion. This was to form a continuation of the coordinated exchange of information which had begun under the auspices of the Organization for European Economic Cooperation (OEEC). Under this program, several member states of OEEC had arrived at agreements for cooperative research on saline water conversion, such as research on vaporization conducted jointly by the Admiralty Materials Laboratory (United Kingdom) and the Central Technical Institute (TNO), Netherlands. Similar agreements were made in the field of electrodialysis and distillation by means of solar energy.

The UNESCO Advisory Committee on Arid Zone Research, at its 13th session, recommended that the organization undertake a survey of institutions and laboratories engaged in research on saline water conversion. A questionnaire was prepared and mailed to interested institutions in the spring of 1958. A summary of the results of the survey, showing the countries and types of research activities in water demineralization is indicated in Table 2.

Conferences and Symposia

The accelerated interest in water demineralization during the past decade is indicated by the numerous meetings

TABLE 2

COUNTRIES ENGAGED IN SALINE WATER DEMINERALIZATION RESEARCH

(Summary of UNESCO Survey)^{1/}

Country	Number of organizations engaged in various types of water demineralization research	Number of organizations engaged in specific types of research ^{2/}									
		Thermal : distillation	Freezing : distillation	Osmosis : distillation	Chemical : distillation	Electrical : distillation	Solar : distillation				
Australia	1	1					1				1
France	9	2	1		5		4				4
Hungary	1				1						
India	4				3		1				1
Iraq	1										1
Israel	3	2	1			1					1
Italy	2	1									2
Japan	9	3	2		3		5				1
Netherlands	2	2					1				
Spain	1							1			
Switzerland	2	2	1								
Union of South Africa	1				1		1				
United Kingdom	9	5			3		4				2
United States	39	21	5	6	6	13					6
Yugoslavia	1		1								
TOTALS	85	38	12	6	22	31					19

^{1/} UNESCO, Report of Advisory Committee on Arid Zone Research, 14th Session, "Survey of Institutions Engaged in Research on Saline Water Conversion," Teheran, Iran, October 1958.

^{2/} As of August 15, 1958.

that have been held throughout the world to discuss various phases of the problem. Table 3 summarizes the more important conferences and symposia.

Sea Water and Brackish Water Characteristics

There exists no clear-cut definition in terms of salinity of sea and brackish water. It is arbitrarily established in this bulletin that water with total dissolved solids content between 1,000 and about 30,000 parts per million (ppm) is termed "brackish". Water of salinity from about 30,000 ppm to about 55,000 ppm is termed "sea water".

Sea Water Characteristics

Sea water is an aqueous solution of dissolved solids and gases which generally contains, in addition, suspended organic and inorganic material. There are about 50 chemical elements known to be present in solution in sea water, of which 40 of the most common are given in Table 4. The water in most oceans of the world contains about 3.5 percent or 35,000 ppm total dissolved solids. Inland seas and lakes may contain water of much higher salinity (for example, the Arabian Gulf water averages 43,000 ppm) while other ocean coastal waters such as bays and estuaries may be diluted by rivers to half or even less of normal sea water salinity. Typical variations of the salinity of ocean and sea water are listed at the top of page 20.

TABLE 3

CONFERENCES AND SYMPOSIA CONCERNED WITH
SALINE WATER DEMINERALIZATION PROCESSES

Sponsoring organization	Location	Date	General subject of meeting	Specific water demineralization topics discussed
United Nations Educational, Scientific and Cultural Organization	Ankara, Turkey	1952	Arid Zone Hydrology	All phases of water demineralization and uses in arid areas.
United States Navy, Bureau of Yards and Docks	Port Hueneme	September 1953	Advance Base Water Supply and Sanitation	Various types of demineralization processes.
University of Arizona, Stanford Research Institute and Association for Applied Solar Energy	Tucson, Arizona	October 31-November 1, 1955	Solar Energy Applications	Solar distillation equipment, observations, economics, etc., 9 papers presented.
United Nations Educational, Scientific and Cultural Organization	New Delhi, India	1956	Wind and Solar Energy	Solar distillation
American Society for Testing Materials	Los Angeles, California	September 20, 1956	Industrial Water and Waste Water	Sea water purification
United States Department of Interior, Office of Saline Water	Washington, D. C.	November 4-6, 1957	International Symposium on Saline Water Conversion	All phases of water demineralization. Approximately 40 papers presented.
United Nations Educational, Scientific and Cultural Organization	Teheran, Iran	October 11-15, 1958	Scientific Research on Arid Lands	All phases of water demineralization and uses in arid regions

TABLE 3 (Continued)

CONFERENCES AND SYMPOSIA CONCERNED WITH
SALINE WATER DEMINERALIZATION PROCESSES

Sponsoring organization	Location	Date	General subject of meeting	Specific water demineralization topics discussed
United States Department of Interior, Office of Saline Water	Washington, D.C.	October 6, 1959	Membrane processes	Progress reports by contractors to Office of Saline Water, conduction membrane research, 15 reports presented.
United States Department of Interior, Office of Saline Water	Carrier Corp., Syracuse, N.Y.	October 14, 1959	Freezing processes	Carrier pilot plant contact refrigerants, rotating freezer, zone-freezing, crystal size, etc., 7 reports presented
United States Department of Interior, Office of Saline Water	Washington, D.C.	November 9-10, 1959	Distillation processes	Materials of evaporator condensers, heat transfer, thermodynamic cycles, scale control, etc.
United States Department of Interior, Office of Saline Water	Port Orange, Florida	December 10, 1959	Solar Distillation	Inspection of solar plant facilities, review of results of research activities
American Chemical Society	Cleveland, Ohio	April 13-14, 1960	Saline Water Conversion	All phases.
California Institute of Technology	Pasadena, California	May 5-6, 1960	Desalting of water	Theory, distillation, electrodialysis and economics.

<u>Body of water</u>	<u>Average dissolved solids (parts per million)</u>
Average of the oceans	about 35,000
Pacific Ocean, off San Diego	33,600
Baltic Sea	7,000
Black Sea	20,000
White Sea	28,000
Salton Sea	36,000
Arabian Gulf	43,000
Red Sea	55,000

TABLE 4

CONCENTRATION OF ELEMENTS IN SEA WATER^{1/}
(parts per million total dissolved solids)

Element	: Concentration : : (parts per : : million) :	Trace elements	: Concentration : : (parts per : : million) :
Chlorine	18,980	Arsenic	0.01-0.02
Sodium	10,561	Iron	0.002-0.02
Magnesium	1,272	Manganese	0.001-0.01
Sulphur	884	Copper	0.001-0.01
Calcium	400	Zinc	0.005
Potassium	380	Lead	0.004
Bromine	65	Selenium	0.004
Carbon	28	Caesium	0.002
Strontium	13	Uranium	0.0015
Boron	4.6	Molybdenum	0.0005
Silicon	0.02-4.0	Thorium	0.0005
Fluorine	1.4	Cerium	0.0004
Nitrogen	0.01-0.7	Silver	0.0003
Aluminum	0.5	Vanadium	0.0003
Rubidium	0.2	Lanthanum	0.0003
Lithium	0.1	Yttrium	0.0003
Phosphorus	0.001-0.1	Nickel	0.0001
Barium	0.05	Scandium	0.00004
Iodine	0.05	Mercury	0.00003
		Gold	0.000006
		Radium	0.2-3x10 ⁻¹⁰

^{1/} Sverdrup, H. U., and others, "The Oceans", Chapter VI, Table 36, p. 176, New York, Prentice-Hall Inc., 1942.

Extraction of Minerals

The extraction and sale of minerals from ocean water is a suggestion frequently brought forth as a means of reducing the cost of water demineralization processing. The various quantities of minerals in cubic mile of sea water are shown on Table 5.

Salt has been extracted from sea water by solar evaporation since ancient times, and this process is still common in California where the heat of the sun can be employed in shallow ponds to evaporate the water. The metal magnesium is now commercially extracted on a large scale by precipitating magnesium oxide by the addition of lime to the sea water. Bromine is also extracted by treating sea water with chlorine. Bromine is employed in the manufacture of dyes, drugs, and anti-knock additives for motor fuels.

All of the sea water conversion processes now being investigated produce a concentrated brine as a by-product. To extract any of the minerals from the by-product would require further treatment and added expense. With the present known methods of separation, the profits would not be sufficient to appreciably lower the cost of converting sea water to fresh water.

Brackish Water

As previously defined for use in this bulletin, brackish water is water containing 1,000 to about 30,000 parts per million of dissolved solids.

TABLE 5

APPROXIMATE AMOUNT OF MINERALS IN
ONE CUBIC MILE OF SEA WATER^{1/}

Mineral	Weight, in tons
Sodium Chloride (common salt)	120,000,000
Magnesium Chloride	18,000,000
Magnesium Sulphate	8,000,000
Calcium Sulphate	6,000,000
Potassium Sulphate	4,000,000
Calcium Carbonate	550,000
Magnesium Bromide	350,000
Bromine	300,000
Strontium	60,000
Boron	21,000
Fluorine	6,400
Barium	900
Iodine	100 to 12,000
Arsenic	50 to 350
Rubidium	200
Silver	up to 45
Copper, Manganese, Zinc, Lead	10 to 30
Gold	up to 25
Radium	about 1/6 (ounce)
Uranium	7

^{1/} Smith, F. G. W., "The Sun, the Sea, and Tomorrow; Potential Sources of Food, Energy and Minerals from the Sea", Charles Scribners, New York, 1954.

It is unfortunate that in many arid areas of the world the only water locally available is from underground supplies which are brackish. In many areas the local inhabitants must either tolerate this water condition or import supplemental supplies of fresh water for their use. In some cases the ground water supply is adequate in quantity to meet the local needs but is unusable due to its brackish quality.

California has many areas where the quality of ground water ranges between 1,000 to 3,000 parts per million total dissolved solids. There are a few areas in California that have ground water with 3,000 to over 10,000 parts per million total dissolved solids.

It is possible for a few wells, that are producing acceptable quality water, to exist inside an area designated as a brackish water area. Quite often these better quality wells degenerate with use to eventually produce brackish water similar to that in the surrounding area.

Some rivers and streams have brackish water with various amounts of dissolved solids depending on the season of the year. For example, the New and Alamo Rivers in Imperial Valley, California, range from about 2,000 to 3,000 parts per million. The Salton Sea, into which these rivers flow, ranges from about 33,000 to 36,000 parts per million.

Desirable Water Quality

For water potable to man there are rather strict limitations regarding the quantities of dissolved solids permissible.

Criteria presented in the following sections can be utilized in evaluating mineral quality of water relative to existing or anticipated beneficial uses. It should be noted that these criteria are merely guides to the appraisal of water quality. Table 6 gives the limiting concentrations of mineral constituents for drinking water, as proposed by the United States Public Health Service and adopted by the State of California. Except for those constituents which are considered toxic to human beings, these criteria should be considered as suggested limiting values. A water which exceeds one or more of these limiting values need not necessarily be eliminated from consideration as a source of supply, but it should be carefully evaluated from the health standpoint before being accepted for drinking.

TABLE 6
UNITED STATES PUBLIC HEALTH SERVICE
DRINKING WATER STANDARDS
1946

Constituent	: :	Mandatory limit, in ppm
Lead		0.1
Fluoride		1.5
Arsenic		0.05
Selenium		0.05
Hexavalent chromium		0.05
		<u>Nonmandatory, but recommended limit</u>
Copper		3.0
Iron and manganese together		0.3
Magnesium		125
Zinc		15
Chloride		250
Sulfate		250
Phenolic compounds in terms of phenol		0.001
Total solids - desirable		500
- permitted		1,000

Criteria for mineral quality of irrigation water have been developed at the University of California at Davis and at the Rubidoux and Regional Salinity Laboratories of the United States Department of Agriculture. Because of diverse climatological conditions and the variation in crops and soils in California, only general limits of quality for irrigation waters can be suggested. A set of criteria based upon studies by the University is given in Table 7.

TABLE 7
QUALITATIVE CLASSIFICATION
OF IRRIGATION WATERS

	: Class 1	: Class 2	: Class 3
Chemical properties	: Excellent	: Good to	: Injurious to
	: to good	:injurious:	:unsatisfactory
Total dissolved solids, in ppm	Less than 700	700-2000	More than 2000
Conductance, in micromhos at 25° C	Less than 1000	1000-3000	More than 3000
Chlorides, in ppm	Less than 175	175-350	More than 350
Sodium, in percent of base constituents	Less than 60	60-75	More than 75
Boron, in ppm	Less than 0.5	0.5-2.0	More than 2.0

The criteria shown in Table 7 have limitations in actual practice. In many instances, a water may be wholly unsuitable for irrigation under certain conditions of use, and yet be completely satisfactory under other circumstances. Consideration also should be given to soil permeability, drainage, temperature, humidity, rainfall, and other conditions that can alter the response of a crop to a particular quality of water.

Energy Requirements for Sea Water Conversion

It can be readily demonstrated, based on established physical and thermodynamic principles, that a certain minimum energy is required to separate the dissolved solids from saline water. Although saline water is in itself a relatively simple system of dissolved salts, it is, on the other hand, a system that possesses considerable stability. As a consequence, relatively large amounts of energy are needed to separate the salts from the water.

Minimum Energy Requirements

The theoretical minimum energy required to convert average sea water is approximately three kilowatt-hours per 1,000 gallons, or 975 kilowatt-hours per acre-foot of fresh water. The figure of 975 kilowatts per acre-foot is not dependent upon the conversion process as it represents only the energy needed to overcome the stability of sea water systems. Actually, Murphy^{1/} and other investigators have shown that a practical minimum energy requirement is approximately four times the above figure and it is improbable that any actual process will operate with less than this latter energy requirement. To this must be added energy for pumping through the conversion plant (about one kilowatt-hour per 1,000 gallons). Thus, the least foreseeable energy requirement is about 13 kilowatt-hours per 1,000 gallons. A power cost of one cent per kilowatt-hour would result in an energy cost per 1,000 gallons of \$0.13 or

^{1/} Murphy, G. W., "The Minimum Energy Requirement for Sea Water Conversion", Research and Development Progress Report No. 9, Office of Saline Water, April 1956.

about \$42 per acre-foot. Each one mill change in the cost of power would result in a variation of \$4.24 per acre-foot under the stated conditions of energy requirements. Conversion plants located at sea level would require additional energy to pump the converted sea water to points of consumption and to furnish required service pressures.

Classification of Process Energy Needs

Of the several methods for demineralizing water, two classifications are useful, the first relating to type of energy required for various demineralizing processes and the second relating to the variation of the required energy with the initial salinity of the water. Table 8 lists the type of energy required for various types of conversion processes. Table 9 lists the same processes as appear in Table 8, divided into two groups. The first group includes all of the processes for which the energy requirement is essentially independent of the initial salinity of the water supply, and the second group includes the processes for which the energy requirement is strongly influenced by the initial salinity.

Those demineralization techniques depending on separation of water from the dissolved solids, such as distillation and freezing, are almost entirely unaffected by the composition and the concentration of solids present. Consequently, all concentrations and types of mineralized water can be purified with almost equal facility by such processes. On the other hand, techniques that remove solids from the water, such as electrodialysis, are markedly affected by the composition and concentration of the minerals present. Consequently,

TABLE 8

TYPE OF ENERGY REQUIRED FOR
VARIOUS CONVERSION PROCESSES

Type of energy	:	Conversion process
Heat		Multiple-effect distillation Multistage flash distillation Supercritical distillation Vacuum flash distillation Solar distillation
Mechanical		Vapor compression distillation Freezing Reverse osmosis
Electrical		Electrolysis Electrodialysis
Chemical		Ion exchange Precipitation

TABLE 9

CLASSIFICATION OF CONVERSION PROCESSES
BASED ON THE VARIATION OF ENERGY
REQUIREMENT WITH INITIAL SALINITY

Type of energy	:	Conversion process
Processes in which the energy requirement is essentially independent of initial salinity.		Multiple-effect distillation Multistage flash distillation Vapor compression distillation Supercritical distillation Vacuum flash distillation Solar distillation Freezing Reverse osmosis
Processes in which the energy requirement depends on initial salinity		Electrodialysis Ion exchange Chemical precipitation

such methods are best suited to the demineralization of moderately brackish or greatly diluted sea water rather than for purifying normal sea water.

Methods of Converting Saline Water to Fresh Water

Methods for separating fresh water from saline water may be broadly classified as distillation processes, freezing processes, membrane processes, and a number of other processes based on chemical and physical laws. While relatively few phenomena have been utilized in demineralizing water commercially, experimental work is being carried on in many fields of saline water conversion. It is the intent of this section to review the basic particulars of several of the existing separation schemes.

Distillation Processes

Thermal distillation is both the oldest and most widely used technique for obtaining fresh water from the sea and accounts for over 90 percent of the installed capacity of demineralization plants located throughout the world. In its most elementary form, it is a means of removing pure water from brine by evaporating the water in a boiler and then conveying the vapor to a cooling device that condenses the vapor into fresh water.

Simple Distillation. A simple distillation process is schematically shown in Figure 1. It requires approximately 800 times as much energy as the theoretical minimum (three kilowatt-hours per 1,000 gallons) discussed earlier in this chapter.

Economy in the utilization of energy in distillation can be accomplished by the re-use of heat as is shown in Figure 2. Multiple re-use of heat is an essential feature of the design of all modern distillation plants and is called multiple-effect or multistage, depending on the detail of the processing. These techniques are described in the following paragraphs.

Multiple-effect Distillation. Multiple-effect distillation, the principal method used in large sea water conversion plants at the present time, is shown in Figure 3. In the multiple-effect technique, steam produced in the first effect is condensed in the following effect. As a consequence, it furnishes heat for evaporating more water from the latter effect. Each effect is operated at a lower pressure than the previous one and the pressure changes correspond to the temperature differences required to produce the flow of heat needed. Plants now exist with various number of effects, the most common being three. Six effects have been employed, which nearly doubles the economy of three effects. The oldest and most advanced development of the multiple-effect distillation process has been for marine applications where high costs to produce fresh water production are justified when space is saved and increased cargo earnings more than offset the cost of the water processing. The first large land-based distilling plants followed marine practice closely. However, recent designs for large land plants have tended to depart markedly from marine practice because of recent advances in technology

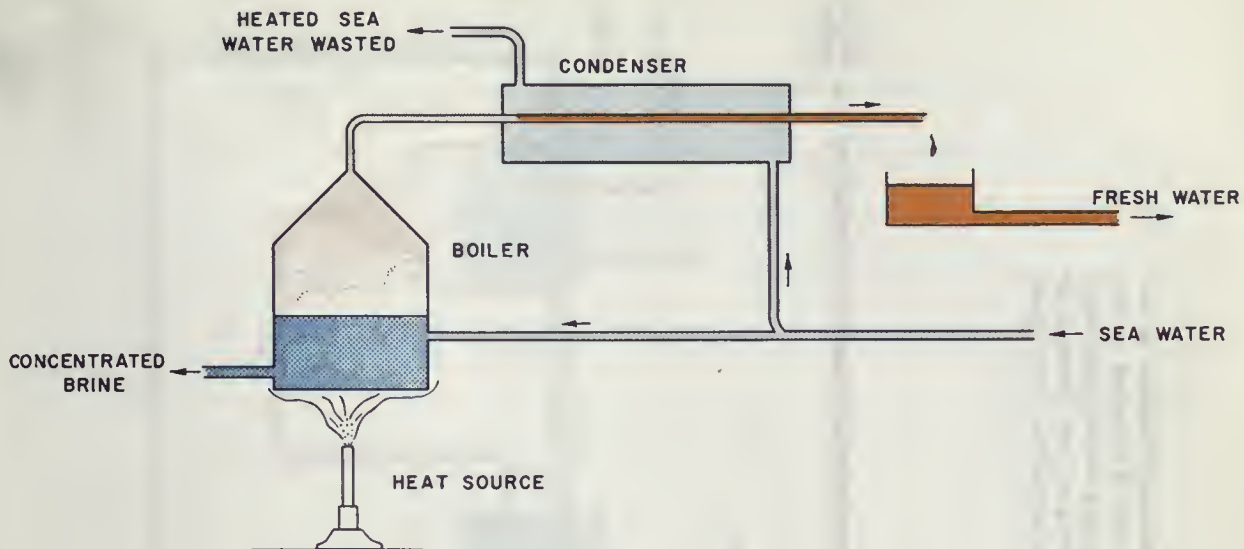


Figure 1
SIMPLE DISTILLATION

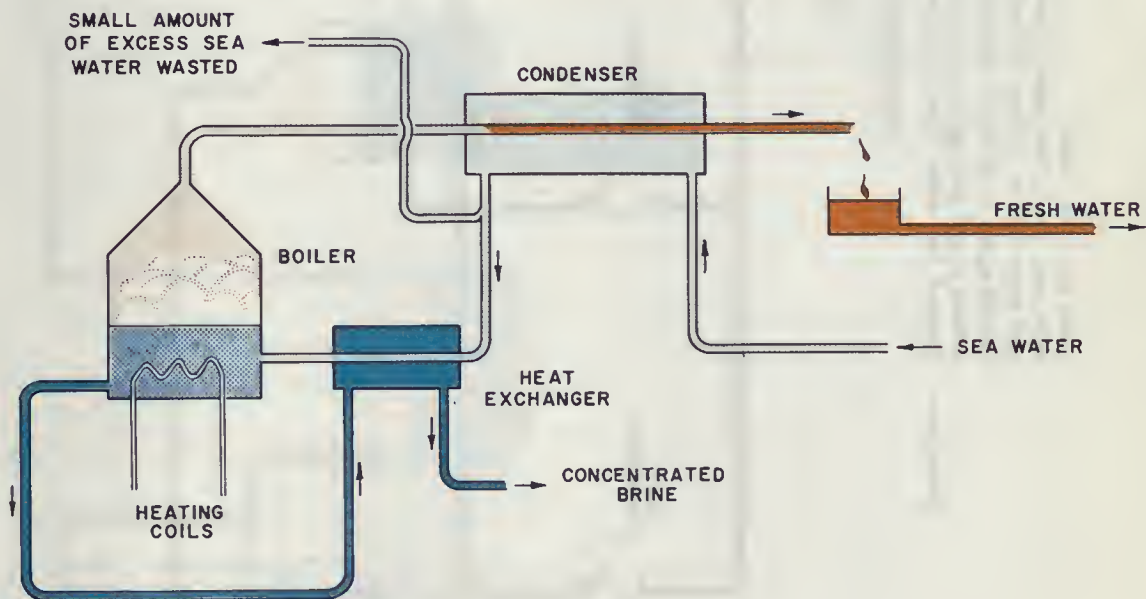


Figure 2
SIMPLE DISTILLATION WITH RE-USE OF HEAT
FROM CONDENSER AND HEAT EXCHANGER

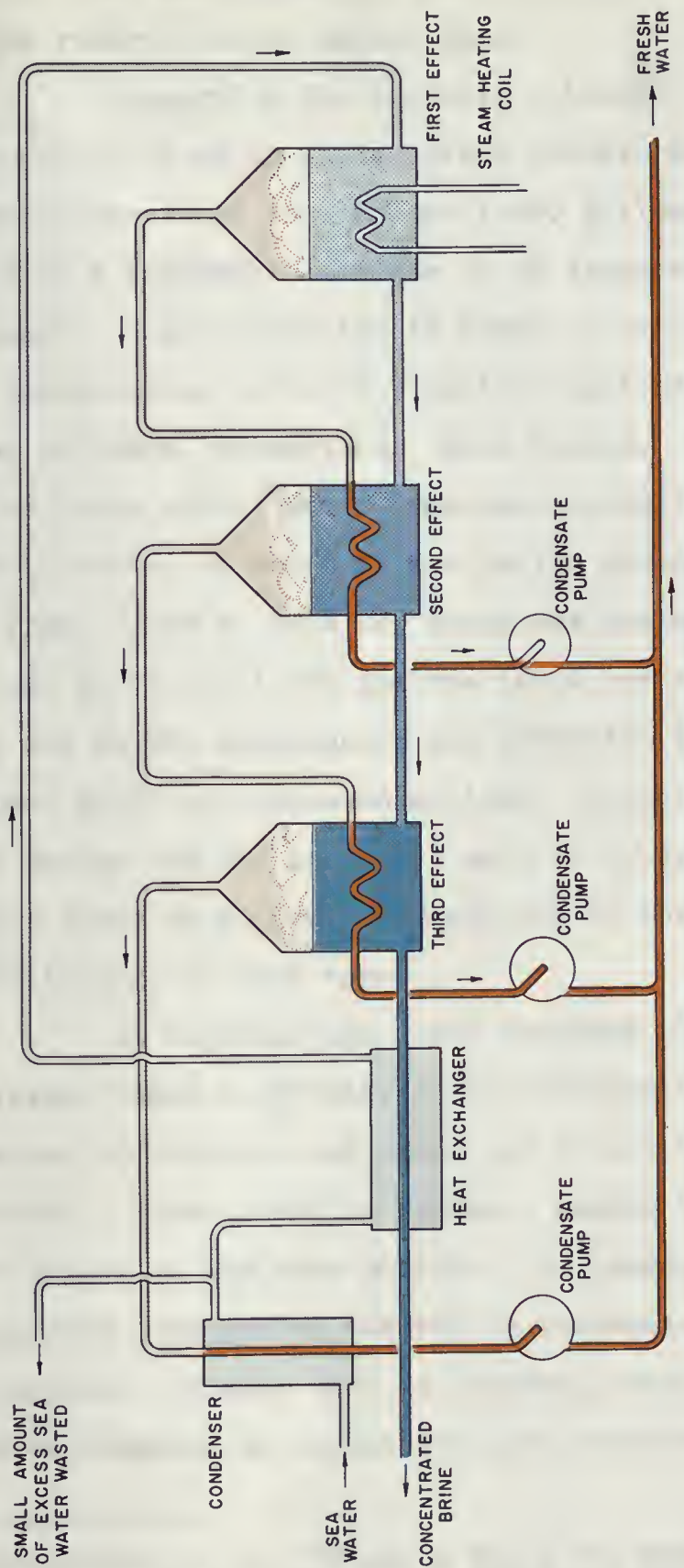


Figure 3
MULTIPLE-EFFECT DISTILLATION

Operation— Entering sea water picks up heat in the condenser and heat exchanger before being heated in the first effect. Steam from the first effect is condensed to fresh water in the second effect. In so doing, heat is given off to the sea water in the second effect which also boils, but at a lower temperature and pressure. This process is repeated in each effect with lower and lower pressure. The last effect uses a separate condenser to condense the fresh water.

and the fact that equipment space requirements on land are not as restrictive as aboard ship.

Concerning the probable ultimate cost of water produced by large multiple-effect plants, Sonderman^{1/} has recently concluded that \$1 per 1,000 gallons (\$326 per acre-foot) is a reasonable minimum to be expected for this type of plant. This conclusion is based on experience gained in the construction of the 2.7 million gallons per day six-effect plant at Aruba, Netherlands West Indies. The capital cost of the Aruba plant, which produces electric power as well as potable water, is about \$4 per gallon per day of capacity. The fresh water at this new plant was estimated during design to cost \$1.75 per 1,000 gallons (\$470 per acre-foot) of which fuel was \$0.80, maintenance and operation \$0.30, and capital charges \$0.65 per thousand gallons. Recent advances in equipment design and the increased sale of by-product power may reduce costs to \$1 per 1,000 gallons in the future for large installations of this type.

An experimental plant designed and built by Professor LeRoy A. Bromley at the University of California utilizes 30 effects, and makes use of rotating heat transfer surfaces. These rotating surfaces render the transfer of heat more effective and make possible the immediate passage of steam from evaporating surface to condensing surface without the extensive piping used in present plants. Mechanical energy must be supplied to rotate the heat transfer surfaces, which

^{1/} Sonderman, G. E., "Today's Price for Fresh Water from the Sea", Consulting Engineer, February 1958.

adds to the cost of the product water. This type of equipment may find application to smaller capacity plants.

Flash Distillation. Flash distillation is schematically indicated in Figure 4 which represents a two-stage plant. In this process heated sea water is released into a closed vessel that is maintained at a lower pressure than the vapor pressure of the heated sea water. As a result, a portion of the sea water flashes into vapor which in turn is condensed to form fresh water. At the present time (1960) from 12 to 30 stages are used in large installations. Economy is expected to be better with the multistage flash plant than with conventional plants of the multiple-effect type (see Glossary for definitions of "stage" and "effect"). In Figure 5 is shown 10 stages in one vessel. The combining of several stages in one vessel permits a saving in both material and labor costs. The California experimental demonstration plant which is to be built at Point Loma, San Diego, will have 36 stages, with as many as 8 stages in one vessel. Figure 6 illustrates how a nuclear reactor can be utilized as a heat source with a multistage flash evaporator to convert sea water. Figure 7 shows the recently completed 26-stage, 100,000 gallons per day sea water conversion plant at Mandalay Beach, near Oxnard, for the Southern California Edison Company.

Vacuum Flash Distillation. The vacuum flash distillation process makes use of two existing water supplies of different temperatures, such as exists between the surface and

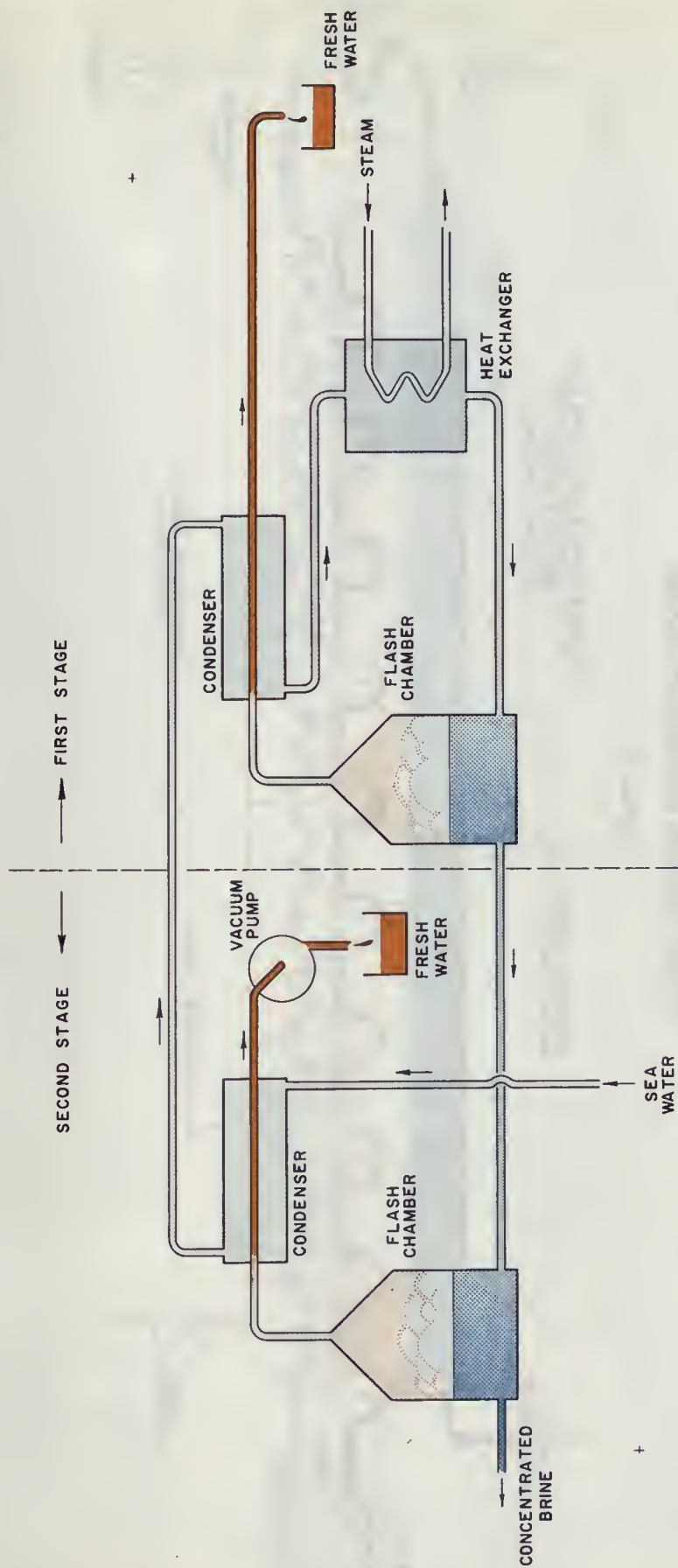


Figure 4

TWO-STAGE FLASH DISTILLATION

Operation— The sea water picks up heat in each condenser before entering the heat exchanger. After being heated in the heat exchanger the sea water boils or flashes in the first stage flash chamber and the steam is condensed to fresh water. The vacuum pump in the second stage causes the sea water to flash at a lower temperature and pressure without the addition of heat.

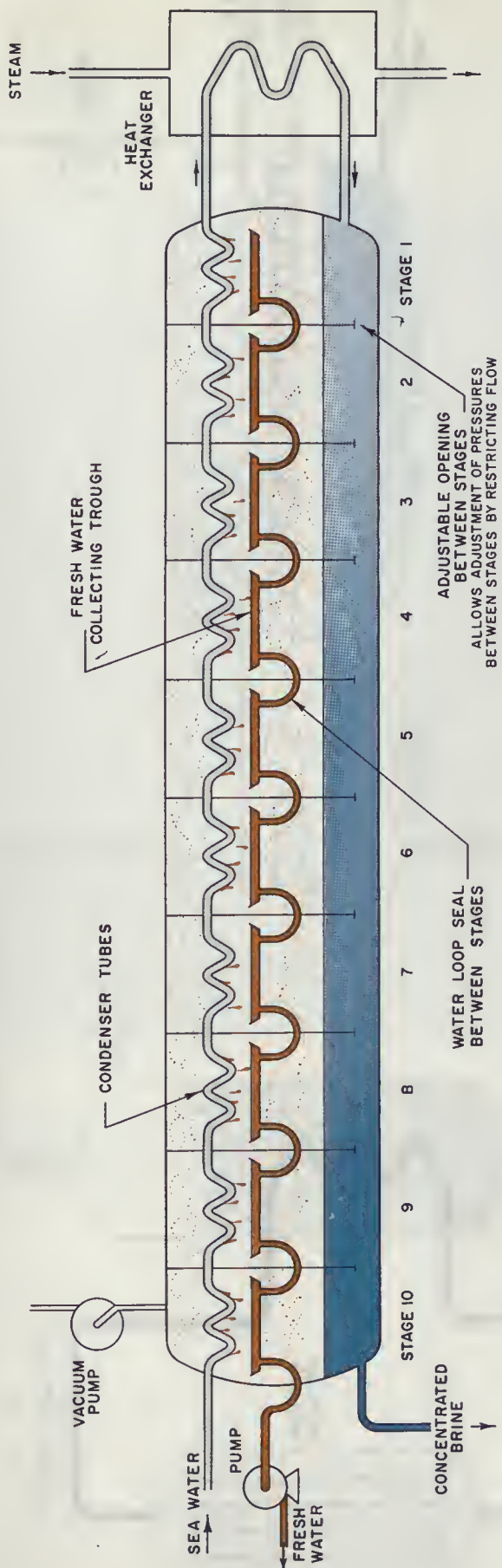


Figure 5

MULTISTAGE FLASH EVAPORATION PROCESS

Note-- For the sake of economy most evaporators are built with a number of stages in one containing vessel. The boiler, condenser and collecting pan are combined in each stage to make a compact unit.

Operation-- The sea water gains heat in each stage in passing through the condenser tubes from stage 10 to stage 1. It is then heated to almost boiling by steam in a heat exchanger. As it enters stage 1 part of the sea water boils or flashes into steam because of the reduction of pressure and is condensed by the condenser tubes. In each successive stage the vacuum gets greater causing more of the sea water to flash into steam and in each stage the steam is condensed by the condenser tubes and drops into the collecting trough.

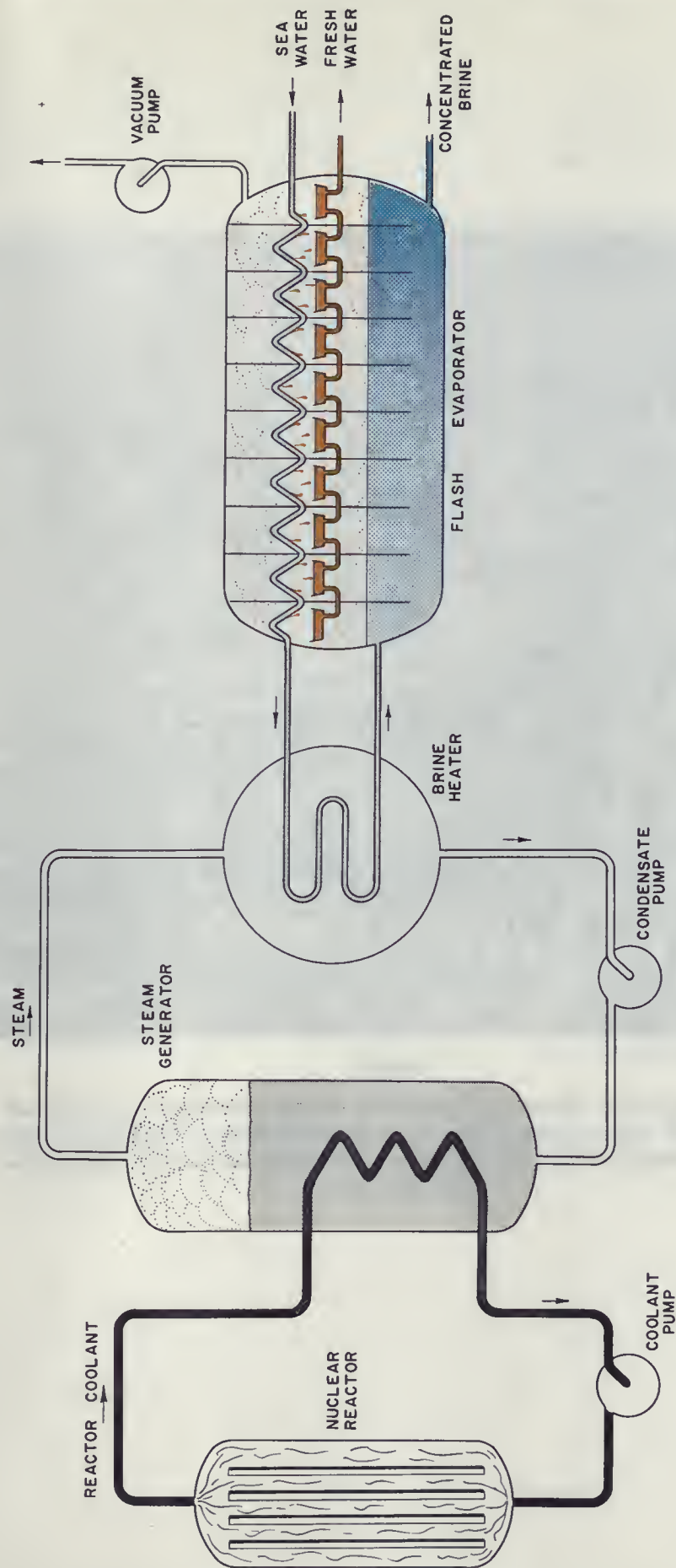
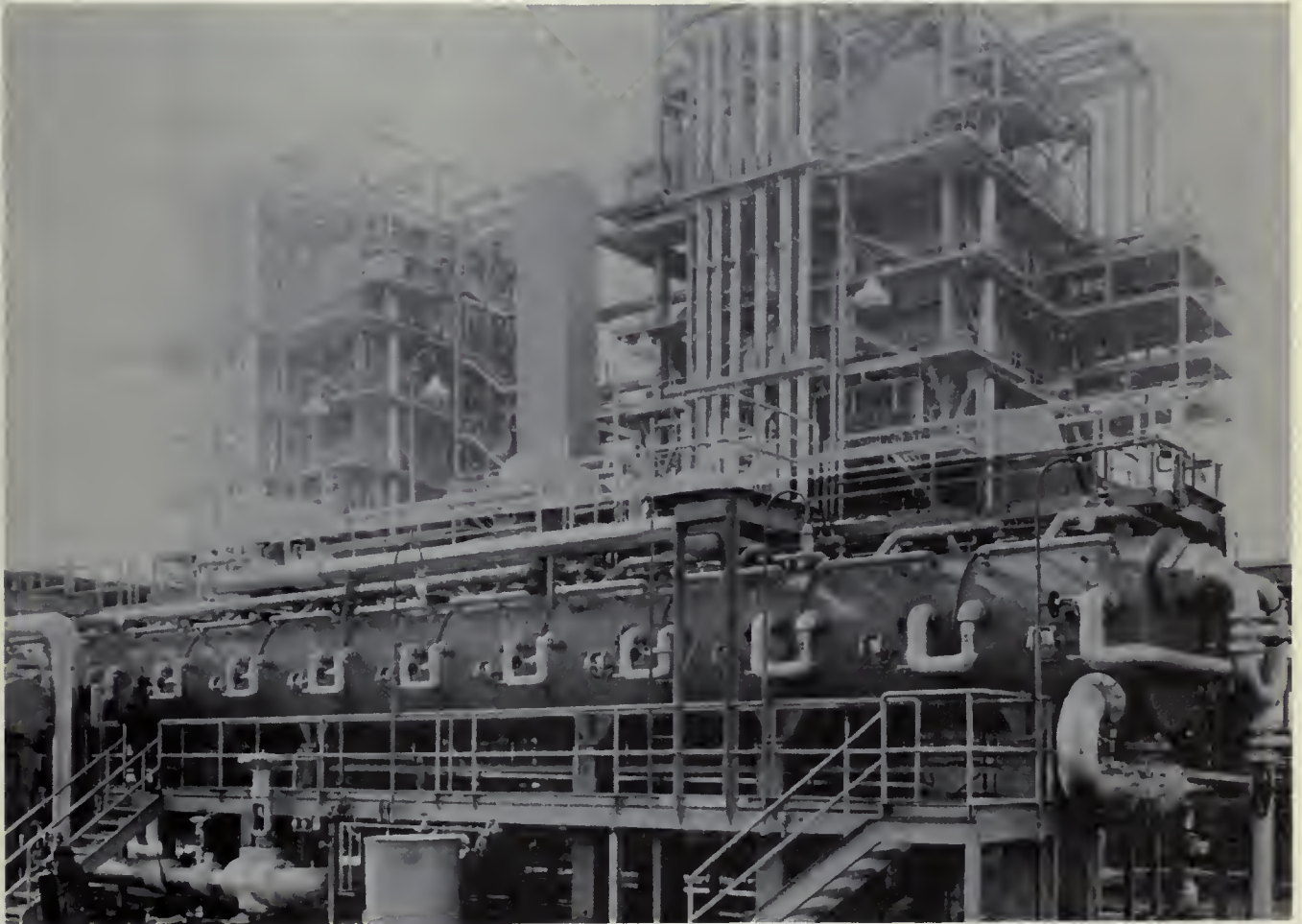


Figure 6
MULTISTAGE FLASH EVAPORATION PROCESS
POWERED BY A NUCLEAR REACTOR



Figure 1: Transformer circuit diagram.



Courtesy Southern California Edison Company

Figure 7

The Southern California Edison Company sea water conversion unit at Mandalay Beach, located adjacent to the power plant facility. The 26-stage evaporation conversion plant has a capacity of 100,000 gallons of fresh water per day.

ocean depths. This scheme has the merit of requiring no fuel energy for the separation, providing two sources of water are available having a temperature difference of at least 20° F. Warm water from the ocean surface is sprayed into a vacuum chamber where a small part of it flashes into steam and the remainder is cooled a few degrees in the furnishing the heat for evaporation. The vapor then passes into a condensing chamber where it is condensed on the outside of cold metallic tube surfaces and collects as fresh water. The cooling is furnished by the cold water from the ocean depths which is circulated through the condenser tubes.

While warm waste or cooling water from some power plants and industries would furnish some small sources of energy for this scheme, the largest application would be that of the ocean itself, where unlimited quantities of water are available. Deep submarine canyons at several locations adjacent to the California coast have been investigated as possible sources of cold water for this process. A temperature differential of at least 20° F. is required between the two sources of supply for minimum operation, and this can normally be attained at southern latitudes by using water from a depth of about 2,500 feet for one source and water from the surface as the other source.

An experimental vacuum flash distillation plant of about 3,000 gallons per day capacity was built at the Richmond Field station of the University of California. This plant is illustrated in Figure 8.

Super-critical Distillation. Figure 9 illustrates the system known as super-critical distillation. This system utilizes the fact that the heat required to vaporize water in its critical state is zero (and is also very small, just below this pressure and temperature). The critical pressure for water is about 3,206 pounds per square inch absolute, and the critical temperature is about 705° F. In this technique, sea water is pumped through a heat exchanger at super-critical pressure. The fresh water produced runs through the same heat exchanger, in the opposite direction, as does also the waste concentrated brine. When the hot sea water leaves the heat exchanger, it is passed into a separately heated vessel where only a small amount of additional heat is required to cause partial vaporization. At this point, the vapor is separated from the brine and is returned to one of the passages in the heat exchanger, while the brine is fed into another return passage in the same heat exchanger.

Several serious problems of design and operation are yet to be solved, including:

1. Selection of suitable materials for the heat transfer surface that can resist the extremely corrosive properties of the very hot sea water.
2. Means for preventing or reducing the rapid deposition of scale.
3. The design of efficient hydraulic turbines and pumps to effectively handle sea water and brine at the temperatures and pressures used in this system.



Figure 8

Photograph by DWR

Experimental vacuum flash distillation plant at the Richmond field station of the University of California.

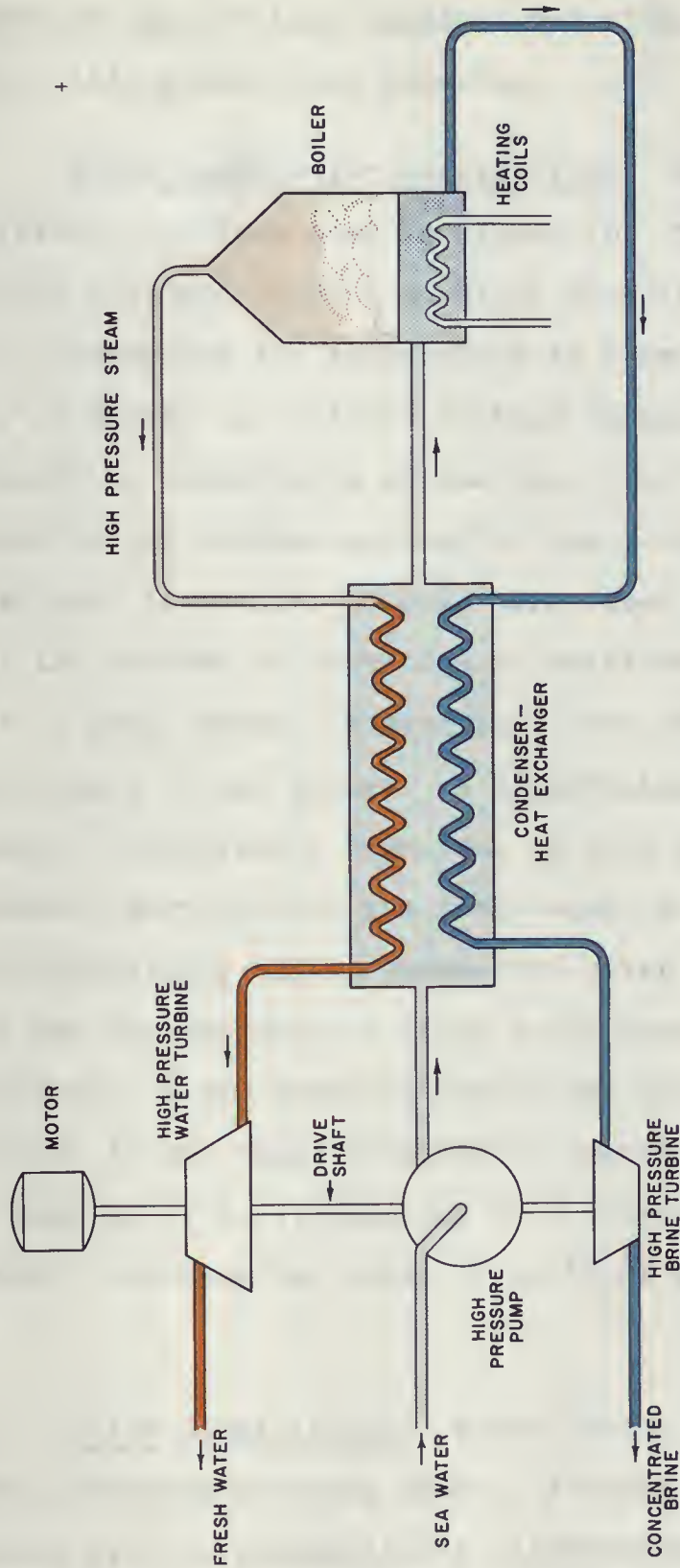


Figure 9

SUPER CRITICAL PROCESS

Operation— When water under high pressure (about 3206 pounds per square inch) is heated to greater than 705 F it reaches a so-called critical condition in which it will change from liquid to steam with very little additional heat. The super critical process makes use of this principle. A high pressure pump raises the pressure of sea water to above 3206 pounds per square inch and as it passes through the condenser-heat exchanger it is heated by the condensing steam from the boiler. A small amount of heat is added to the sea water in the boiler and steam is formed. The steam is then condensed to fresh water in the condenser-heat exchanger and the pressure it still contains is used to help run a turbine which operates the high pressure pump. Additional power must be supplied to the high pressure pump over and above that supplied by the high pressure brine and water turbines.

Up to the present time, a complete solution of these technical difficulties has not been obtained and little practical application of this process has resulted.

Vapor Compression Distillation. Vapor compression distillation is illustrated in Figure 10. This process makes use of the well-established physical principle that when a vapor is compressed its temperature is raised. Considerable economy of energy is achieved by this technique of increasing temperature by compression of the gas. The hot steam is then condensed in the heating section of the evaporator where the released heat is used to produce more steam and as a consequence, the economy of operation is relatively high. There is, however, a small amount of auxiliary heat required to make up for the losses in the system. A disadvantage of the vapor compression distillation technique is that the plants are complicated, particularly the large size, and the capital costs are correspondingly high. Commercial units as large as 50,000 gallons per day capacity of fresh water have been constructed and operated. A new rotating device for increasing the transfer of heat in the vapor compression system has been invented by Dr. Kenneth C. D. Hickman, and this invention gives promise of markedly reducing the costs of units of relatively small size.

Solar Distillation. Distillation by solar heating has been practiced for many years. A solar still of the greenhouse type is schematically illustrated in Figure 11, and various types of experimental solar distillation apparatus at

Richmond Field station, University of California, are shown in Figure 12. As can be seen in Figure 11, the rays of the sun pass through a glazing of glass or plastic and heat the saline water in the bottom insulated tray. Vaporized water is conveyed by convection and condenses on the inner glazing surface and runs down into collecting troughs. An obvious advantage to solar distillation is that the energy (insolation) is free, and in warm arid climates the source during daylight hours is fairly constant. A disadvantage is the low efficiency of the system, the large amount of land needed to produce sizeable quantities of fresh water, and the correspondingly high capital costs. A series of experiments with various forms of solar distillation equipment have been conducted at the University of California during the past seven or eight years. In addition, test work under the auspices of the Office of Saline Water, United States Department of the Interior, has been conducted by various institutions such as the New York University and the Bjorksten Laboratories, Madison, Wisconsin. The Office of Saline Water also operates a test facility at Port Orange, Florida. Experiments have been carried out on similar units by investigators in Algeria, Australia, Cyprus, Italy, and in the Virgin Islands. Several semi-commercial plants have been built in Algeria and Australia. Up to the present time, no large-scale commercial installations have been constructed. The largest solar plant known was the plant built and operated in South America in the 1870's, which was described previously on page 8.

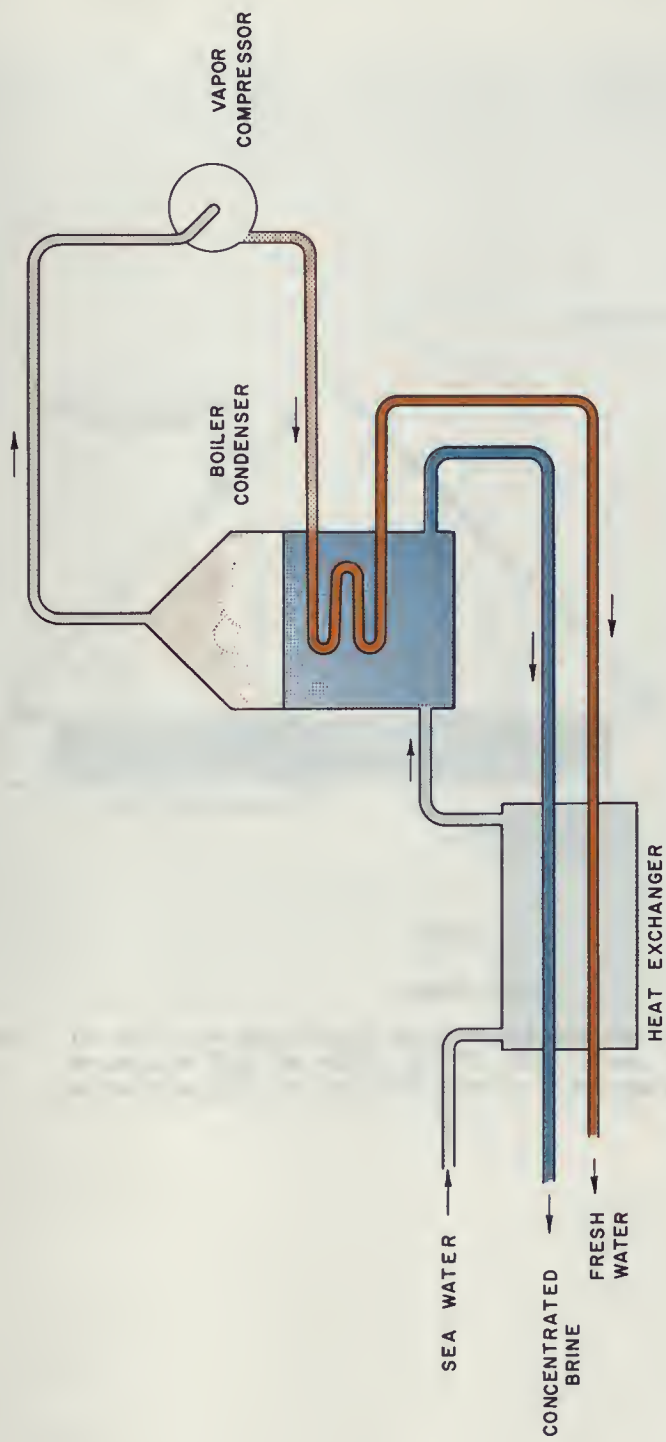


Figure 10

VAPOR COMPRESSION PROCESS

Operation—

The vapor compressor takes in water vapor from the boiler-condenser and compresses it to both a higher pressure and temperature. This vapor passes through the coil in the boiler-condenser and heats the sea water while the vapor is condensing into fresh water. The heat exchanger salvages heat from the discharged concentrated brine and fresh water for re-use in the boiler-condenser.

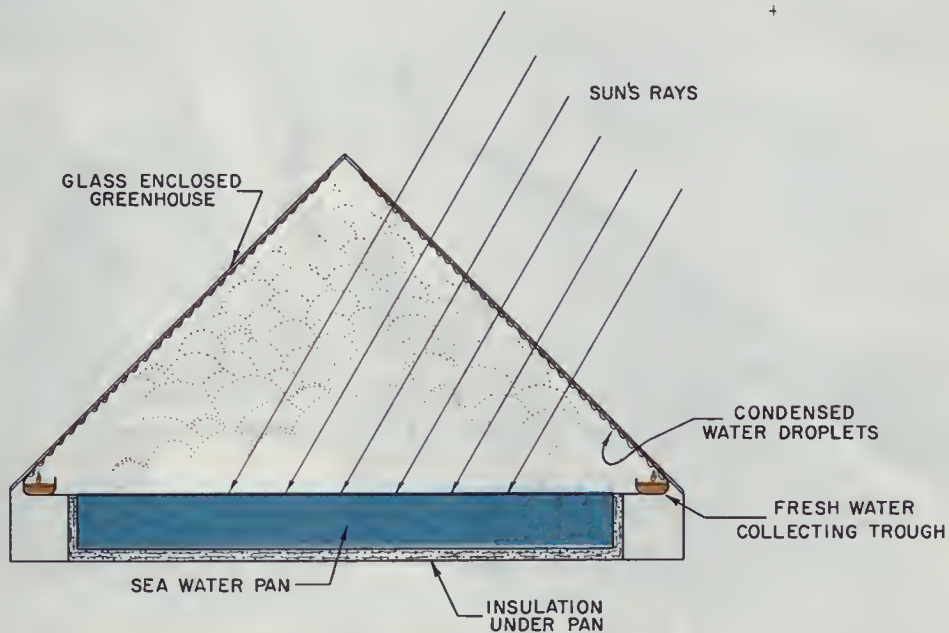


Figure 11

SOLAR STILL

Operation— The sun's rays pass through the glass and heat the sea water in the pan to a higher temperature than the outside air. The moisture from the heated sea water condenses on the cooler glass top and trickles into the fresh water collecting trough.



Figure 12

Photograph by DWR

Experimental solar distillation apparatus at the Richmond field station of the University of California.

Research has indicated that, on a year-around basis, only about one-half of the solar energy striking a horizontal surface is absorbed as heat by the fresh water produced in simple solar stills. This results in production rates, for California latitudes, of approximately one gallon per day for each eight square feet of horizontal collector surface. This would amount to about four acre-feet per year for each acre of solar stills. The construction cost of simple solar stills is about \$10 per gallon per day of capacity at the present time which contributes to an excessively high product water cost.

Freezing Process

Freezing, as a method of water demineralizing, has been frequently suggested since when sea water is solidified only the pure water forms crystals while the dissolved minerals remain in solution as brine. The energy requirements are also attractive, as the latent heat of fusion is only about one-seventh that required for vaporization. One type of freezing technique is illustrated by Figure 13. A major problem hampering the commercial development of this technique is the difficulty encountered in separating the brine from the ice crystals since small amounts of brine are trapped between crystals as the ice is formed. Systems for separating the ice from the brine involve one of the following, viz.:

1. Compression of the ice so that the brine is forced out.
2. Centrifuging and washing the ice.

3. The migration of pockets of brine to the ends of solid ice cylinders induced by the movement of a heated zone along the cylinder.

4. Counter-current flow of recycled fresh water through a wash column.

Efforts to separate the ice and brine by centrifuging have been conducted by a number of experimenters. Up to the present time, results have not been encouraging as only about 20 percent of the sea water has been recovered as fresh water, the remainder of the water being needed for washing. The Carrier Corporation, under the auspices of the Office of Saline Water, United States Department of the Interior, has constructed and tested a small unit employing a freeze-evaporation process. In this technique, a suspension of ice in brine is formed when cold sea water is sprayed into a vacuum chamber. The suspension is then pumped out of this vacuum chamber into the bottom of a washing column where fresh water added for washing flows downward against the ice particles which are rising because of their buoyancy. Brine, diluted with wash water, is then removed from the bottom of the washing column and fresh water is obtained from the melted ice.

Membrane Processes

Electrodialysis. The process known as electrodialysis is, as a practical means of demineralizing, a fairly recent development. This process, diagrammatically shown in Figure 14, makes use of the electrical characteristics of the mineral constituents of brackish or sea water. For example, common salt (NaCl) when dissolved in water dissociates into charged atoms

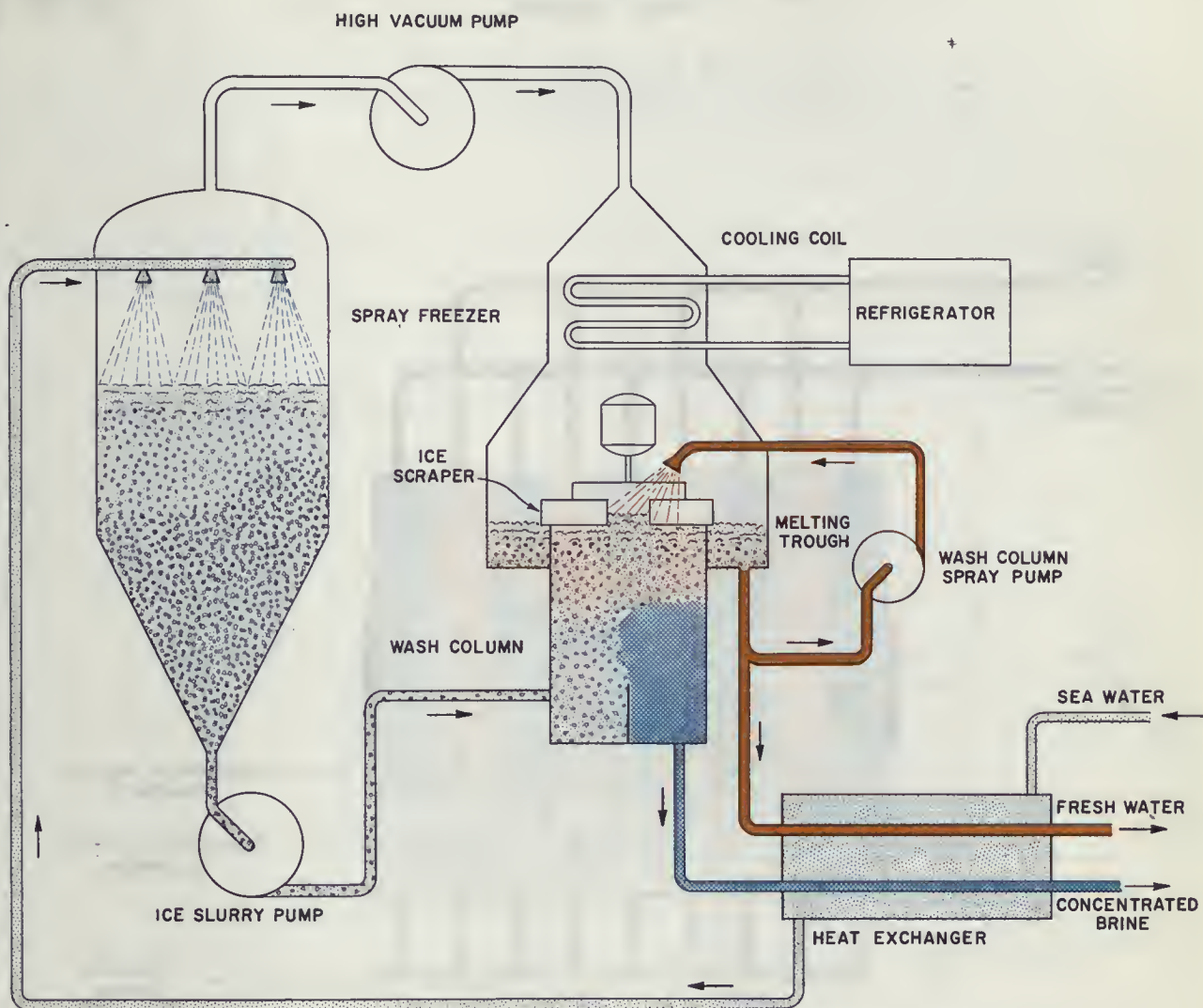


Figure 13

FREEZING PROCESS

Operation— Sea water is cooled in the heat exchanger and is then sprayed into the freezer which is maintained at a temperature of 24F and a high vacuum of 3mm of mercury. At this temperature and vacuum about half of the sea water is frozen into an ice and brine slurry. The wash column washes out the brine with a counter-current fresh water stream and the ice is melted into fresh water.

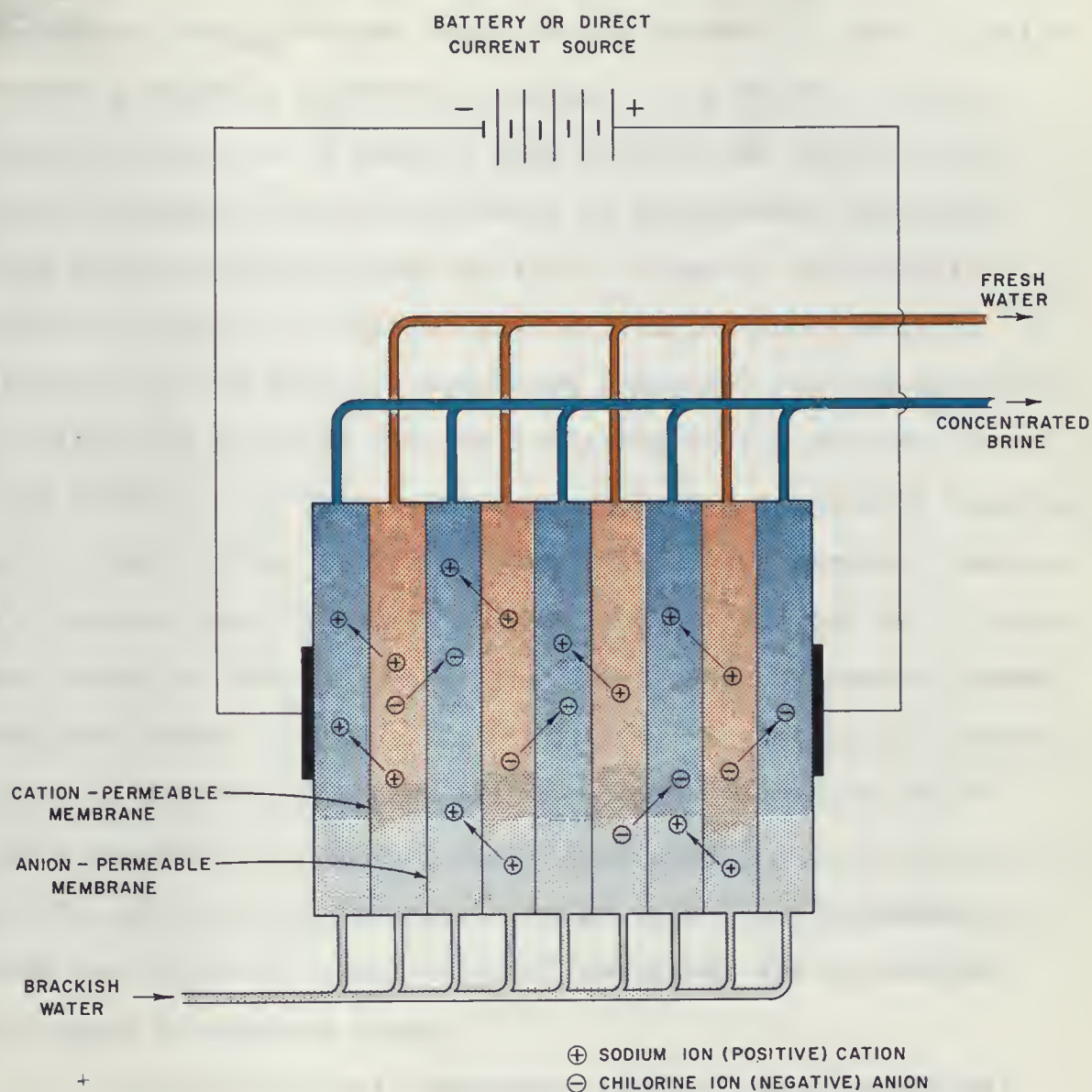


Figure 14

ELECTRODIALYSIS PROCESS

Operation—As brackish water flows through each passage between membranes, an electric current attracts the negative or anions to the right and the positive or cations to the left. The cation permeable membrane allows only positive ions such as sodium to pass through and only in the one direction. The anion permeable membrane allows only negative ions such as chlorine to pass through and only in the one direction. As a net result fresh water is formed in alternate passages.

called ions, one type being sodium ions (termed "cations"), each of which carries a positive electrical charge, and the other type being chlorine ions (termed "anions"), each of which carries a negative electrical charge. If a flow of direct electrical current is made to pass through the mineralized solution between two plates (known as electrodes, one plate being electrically positive while the other is electrically negative), then the positive sodium ions (cations) will be attracted to the negative electrode (cathode) and the negative chlorine ions (anions) will be attracted to the positive electrode (anode). By this technique, employing a suitable trapping device, most of the sodium and chlorine can be removed, leaving as a product water greatly reduced in dissolved solids. Successive stages or repetitions of the above basic processing permit demineralization to any extent required. In the actual process, stacks of plastic membranes are used which are selective to either positive or negative ions, thus allowing only sodium ions or only chlorine ions to pass through into other compartments. These two types of "ion selective" membranes are alternated throughout a membrane stack.

Electrodialysis equipment is still in a relatively early stage of development and extensive operating experience on large plants is limited. An electrodialysis plant located at Bahrein in the Middle East has the longest period of operation, having been installed in 1955 and enlarged to a total daily capacity of 86,400 gallons in 1957. A plant with a capacity of about 2,800,000 gallons per day of potable water

is being constructed in South Africa, to reclaim saline water encountered in gold mines.

In 1959, a plant was constructed and placed in operation by Ionics, Inc., of Cambridge, Massachusetts, at Coalinga, California, having a capacity of 28,000 gallons per day. Figure 15 shows the inside of the Coalinga plant. Ionics has engaged in development of this process for a number of years and the total capacity of all electrodialysis plants, constructed by the firm now (1960) approximates about 600,000 gallons per day.

At present, membrane replacement costs are excessive, being very nearly 50 percent of the operating costs. Undoubtedly, continued development of reliable membranes will lead to reduced initial costs as well as increased life, with the result that future costs will be less. Electrodialysis has an advantage over distillation techniques in that the energy required is proportional to the weight of dissolved minerals removed rather than being proportional to the weight of water produced. As a consequence, electrodialysis is well adapted to the demineralization of most brackish water where the amount of minerals to be removed is relatively small, with the consequent small energy requirements. In some areas this process may eventually compete with the cost of importation of natural water. Considerable use will probably be made of the technique of "blending" with high quality water supplies to improve the overall quality of water supplies from brackish sources.

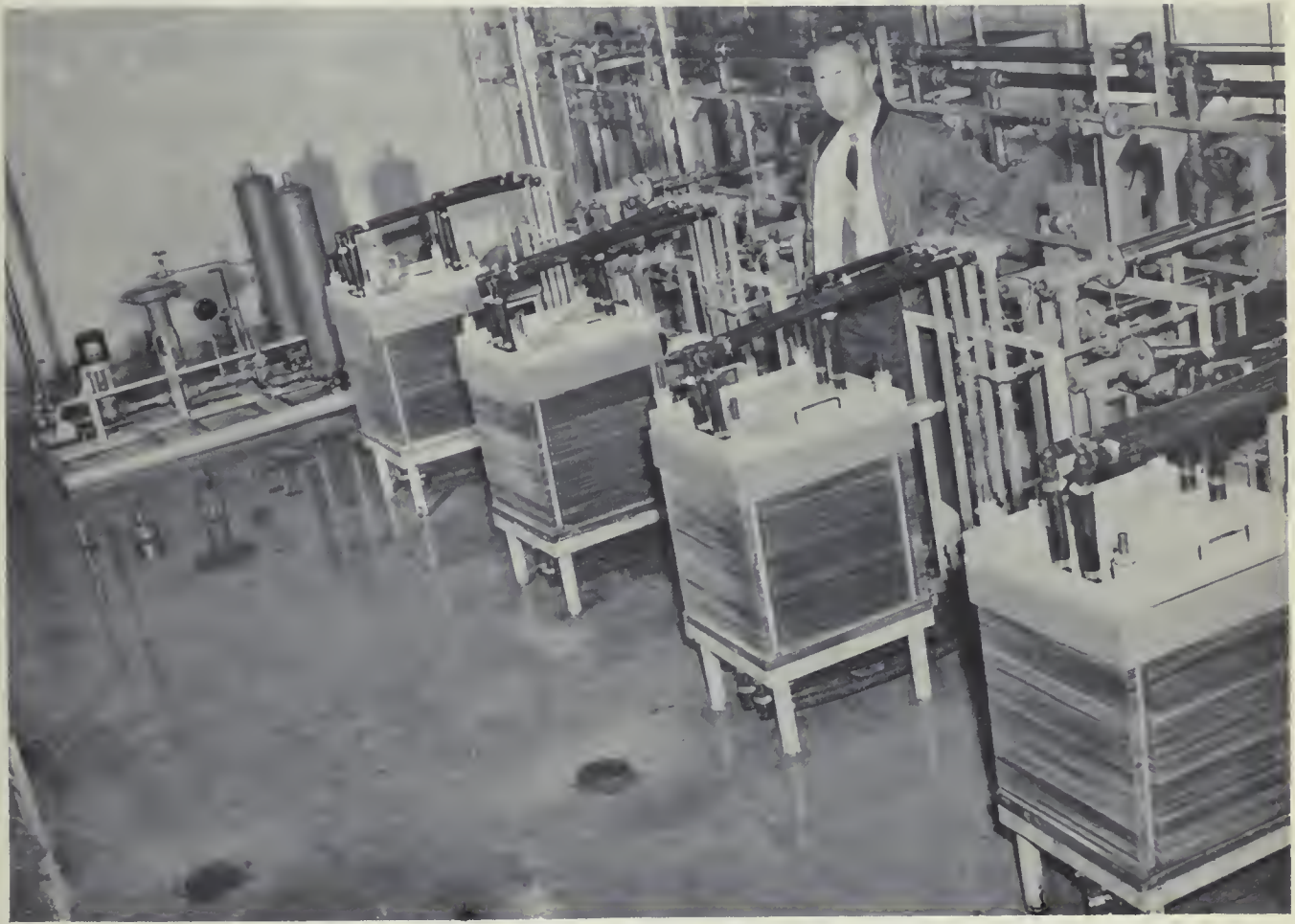


Figure 15

Courtesy City of Coalinga

The brackish water conversion plant at Coalinga, California. This plant is of the electrodialysis type and has a capacity of 28,000 gallons per day.

Reverse Osmosis. Osmosis is the process in which a dilute solution passes through a membrane to a more concentrated solution. Reverse osmosis as the word implies, is the reverse of the normal process of osmosis. In the reverse process pressure is applied to the concentrated solution (more than 370 pounds per square inch for sea water) to overcome the osmotic pressure and force the flow from the more concentrated solution to the dilute solution. As a result of this reversed flow, more dilute solution (demineralized water) is formed.

The University of California at Los Angeles has done considerable work with this process. Some of the difficulties are the slow rates of flow and the short lives of the membranes under the pressure required.

Other Conversion Processes

Ion Exchange. The ion exchange technique has been in wide use for treating water for use in steam generating plants and for domestic water softeners. The principle of a normal ion exchange process is that the water containing ions of a substance to be removed ("A" ions) is caused to trickle through a bed of granules (ion exchange resin) containing ions of a substance acceptable for the proposed use of the water ("B" ions). The "A" ions then exchange places with the "B" ions, the granules become coated with "A" ions, and the water leaves the bed containing the "B" ions. When the supply of replacement ions is depleted, the flow of product water is stopped and the granules are regenerated by flushing a concentrated solution of "B" ions through the granule bed. In the flushing operation,

the granules are forced to exchange the "A" ions for the "B" ions because of the high concentration of the latter. The regeneration cycle can be repeated many times. The main factor inhibiting the use of this method for sea water conversion is the high cost of ion exchange materials.

In the case of the home water softener, calcium ions in the entering hard water are exchanged for sodium ions in the softener or ion exchanger. The sodium ions in the product water are not so detrimental and permit the formation of soap suds; hence, the water is considered as being softened. When the home water softener is depleted, it can be regenerated with a concentrated solution of common salt (sodium chloride).

Industrial ion exchangers operate on the same principle, but use various types of ion exchange materials in order to obtain the type of product water required. In some cases, industries (steam generating plants in particular) use this process to completely demineralize water for their use.

The University of California has experimented in the use of salts of volatile materials for the replacement ions, followed by the recovery of the volatile components from the product water as gases and their re-use as gases in the regenerating process. So far, the work has utilized ammonium bicarbonate, yielding ammonia and carbon dioxide gases when heated. These gases are then dissolved and used in the regenerating solution. The general conclusion is that the particular system studied requires an excessive amount of heat energy for the liberation of the gases. However, since this high heat

requirement is due to the nature of the ammonium bicarbonate, a search is being made for materials requiring less heat energy for the liberation of the gases.

Separation by Solvents. The separation of fresh water from sea or brackish water by solvents is an interesting concept that depends on the ability of a liquid to absorb large quantities of water from a saline solution. By this means, it is theoretically possible to add solvents to saline water, thus dissolving a portion of the water and concentrating the minerals in the remaining brine. The organic solvent containing water is separated from the brine and the fresh water is then separated from the organic solvent. To be effective, a solvent is needed that exhibits sharp solubility changes with temperature, and has a high selectivity for water over salt.

Precipitation. Proposals have been made to use chemicals which when mixed with sea water would precipitate the salts into an insoluble form. These insoluble salts could then be removed by sedimentation or filtration. The high cost of chemicals which have been used in laboratory trials for this process indicates that the process is too expensive to produce large quantities of fresh water economically. If a less costly recovery process can be discovered to reclaim the expensive chemicals for re-use, this process could be very promising.

Algae Experiments. It has been found that certain algae absorb the unwanted salts from sea water. This suggests several possible schemes for demineralizing sea water.

Experiments at the University of California at Los Angeles are being conducted with algae grown in a combination of sewage effluent and sea water, and are primarily concerned with measurements of the capacity of the algae to absorb the minerals from sea water. Favorable results would lead to the installation of a small pilot plant. Also, other studies at Richmond, California, have grown out of the very extensive work done there on sewage treatment by algae. Resources Research, Inc., has studied several species of algae which concentrate sodium. One species was able to maintain an internal concentration of sodium which was twice that of the medium. The medium in this case was about 10 percent sea water.

Department of Water Resources Activities

In order to keep abreast of rapid developments in the sea water conversion and nuclear energy field and to apply these techniques to water resources developments, a legislative subcommittee in 1958, recommended that the Legislature support studies on the application of saline water conversion and nuclear energy to water projects under the Department of Water Resources. At that time, a unit known as the Applied Nuclear Engineering Unit was established in the department to engage in activities in both the saline water conversion and the nuclear energy field. The various phases of these activities in the field of saline water conversion are described below.

Department of Water Resources-- Office of Saline Water Cooperation

By virtue of a provision in the Saline Water Act (Public Law 448, July 3, 1952) permitting the Office of Saline

Water, United States Department of the Interior, to cooperate with state and public agencies, and through the natural desire of the Department of Water Resources to take full advantage of the information accumulated in the federal program, the State of California entered into a formal cooperative agreement with the Office of Saline Water in March 1958. California was the first state to participate in such an agreement, being followed by New Mexico in 1959. The agreement between the Office of Saline Water and the State of California calls for the mutual assistance and exchange of information on techniques and economics of salt water conversion, and on the programs of each agency relating to water problems in general.

Two projects in the federal-state cooperative program are of special importance. One is the department's participation in an engineering study contract covering a distillation conversion plant combined with a nuclear reactor as a heat source, and the other is participation in the design, construction, and operation of a demonstration sea water conversion plant to be built in California.

The study contract was awarded to the Fluor Corporation of Los Angeles and involved an engineering design study and preparation of a cost estimate for a 50,000,000 gallon per day conversion plant utilizing a multistage flash distillation system, and employing a pressurized water-type nuclear reactor plant of 370 thermal megawatt capacity as a source of heat. A similar engineering design study was made by the Fluor Corporation for a 1,000,000 gallon per day plant including either a reactor or

a conventional boiler, using data developed in the study for the larger plant. The cost of these studies was about \$107,000, of which the Department of Water Resources contributed \$40,000, in the belief that much promise in the sea water conversion field lay in nuclear energy as a heat source and in the multi-stage flash system as a distillation process.

Department of Water Resources--
University of California Cooperation

The Department of Water Resources and the University of California have a common interest in achieving demineralization of saline water at a cost sufficiently low to be useful for agriculture, municipal, and industrial purposes in California. In order to coordinate the conversion activities of these state agencies to produce maximum benefits, a cooperative agreement between the department and the University was entered into early in 1958. Under this agreement, close liaison and cooperation have been maintained between the University and the department. The University's research and development facilities are located at the Richmond Field station near the Berkeley campus, and also at the Los Angeles campus. Occasional staff meetings are held at the Richmond Field station, which representatives of the department are invited to attend. Also, occasional meetings involving the research group at the Los Angeles campus are attended. The role of the University is to give major attention to the less well-developed methods, conducting research and experimentation with small pilot plants where deemed desirable. The department, through its statutory responsibility for water resources planning, concerns itself with applications of saline

water conversion as a supplement to conventional water development projects.

The research program of the University of California has been under way continuously since 1951. Its purpose is to search for methods of demineralizing large volumes of sea water at a low cost. "Low cost" is interpreted as meaning costs competitive with normal water supplies, for which maximum prices in California are about \$125 per acre-foot for municipal uses and about \$40 per acre-foot for irrigation purposes. The University's program has involved extensive investigative and experimental work on many different processes, resulting in valuable contributions to the field of saline water conversion. Its work through the years has included analytical studies, laboratory experimentation, and some pilot plant construction and operation. Objectives are both the improvement of existing methods and the development of new processes.

Among the major projects now under way is the testing of a 28-effect rotating distillation plant, 4 feet in diameter, which was recently constructed at the Richmond Field station of the University of California. Preliminary tests have been made using both city water and water from the San Francisco Bay. Water of high quality (less than 5 ppm) has been obtained from the tests.

Experimentation is continuing on the vacuum flash distillation process utilizing low temperature differences. A pilot plant at the Richmond Field station with a capacity of 3,000 gallons per day is being used for this project (see Figure 8). Studies are being conducted on the phenomenon of

fog formation during evaporation and the effect on heat transfer factors of the presence of air in the steam formed by the flashing of the warm sea water.

Equipment is presently being assembled at the Richmond Field station to test the possibilities of an immiscible fluid heat transfer cycle. This process would allow a high rate of heat to be transferred by direct contact from an immiscible fluid to sea water. This scheme would eliminate the expensive tubing required in conventional heat exchangers and the attendant problem of scaling of metallic surfaces.

The University of California at Los Angeles has carried on extensive research with the reverse osmosis process, and has been successful in developing a membrane which can filter out potable water a hundred times faster than previous commercial films. A pressure of 1,500 pounds per square inch was required in experiments to effectively separate potable water from the sea water. The University has recently designed a 500 gallon per day plant which will aid in gathering design and cost information for the design of a 25,000 gallon per day plant.

Other phases of research in saline water conversion carried on by the University of California are mentioned in other sections of this chapter.

Engineering Study Contracts

Several contracts have been awarded by the Department of Water Resources to private firms for studies on sea water conversion. Stanford Research Institute, for example, was

engaged by the department to make a study on the impact of saline water conversion on a proposed project (included in the State Water Facilities recently authorized by the California Legislature) for delivery of water from the northern to the southern part of the State. The institute's conclusion was that conversion in the foreseeable future did not offer an economic alternative water source to the conveyance of natural fresh water.

A study was performed by the Department of Nuclear Engineering, University of California, financed jointly by the University and the Department of Water Resources, involving the economic evaluation of two types of nuclear reactors (pressurized and boiling water) as the source of heat for saline water conversion. The study revealed that the heat costs of these reactors (of thermal power greater than 400 megawatts) are not at present competitive with steam from fossil fueled plants. The costs of steam from the nuclear plants studied were in the range of \$0.54 to \$0.65 per million Btu.

Jacobs Engineering Company has completed a study for the department on the possibilities of controlling the shape and size of ice crystals to obtain a higher efficiency from the freezing conversion process. If large uniform ice crystals can be grown, the problem of entrained sea water among the crystals will be less and the economy of separation will be greater. Jacobs developed a freezing method using carbon dioxide in the saline system to depress the freezing point and induce controlled supersaturation, which should result in the

formation of such crystals. The idea seems promising and further work on this approach is being considered.

Kaiser Engineers, Division of Henry J. Kaiser Company, completed for the department an engineering survey of waste heat availability for saline water conversion in California. This survey investigated waste heat given off by industries and utilities within five miles of the coast line. This survey is covered in more detail in Chapter IV under the section on "Utilization of Waste Heat".

The Fluor Corporation has completed an investigation of a multistage flash evaporation plant using solar heat as the source of energy. This scheme showed some promise in a preliminary investigation since the solar heat was re-used in a number of stages. However, the final report concluded that it would not be economically feasible to produce water by this means. This study was initiated by the Department of Water Resources, but the Office of Saline Water contributed a portion of the cost.

The Applied Nuclear Engineering Unit in the Department of Water Resources has made use of material from other technical specialists in the Department of Water Resources that pertained to saline water conversion. One such investigation was an inventory of the principal saline water sources in the State, and a consideration of the economics of reclaiming such waters for agriculture or domestic use. Another study carried on by the department was the gathering of data on winds to determine whether there was any possibility of harnessing this power for

application to saline water conversion. No site was located in California sufficiently favorable to justify an engineering study of a wind power generator.

A great many schemes have been submitted to the Department of Water Resources by the interested public, describing processes for converting sea water to fresh water, or tapping energy from some unconventional source. Each scheme has been diligently reviewed by the engineers in the department, and in several cases, the scheme has been referred to the sea water research group at the University of California for further study. No proposed scheme yet received has been sufficiently novel or practical to justify development.

Research and Development Programs by the
Office of Saline Water, Department of the Interior

Noteworthy stimulus was given to efforts to investigate means of developing improved demineralization techniques by the establishment, in 1952, of a program by the Department of the Interior to encourage private scientific interest and activity in desalting of sea water. The Office of Saline Water was organized to direct this activity and was given limited funds to support conversion research and development. Three years later, the authority for the program was enlarged and provision was added for devoting part of the fund to the support of process research in other nations.

The act creating the Office of Saline Water, Public Law 448-82nd Congress, 1952, proved to be a powerful scientific and technical stimulus. One result of its efforts was the reinforcement of technical activity abroad as well as in the

United States, bringing about a valuable international exchange of information on saline water conversion.

The Office of Saline Water, upon its establishment, undertook an extensive survey of scientific and technical knowledge and processes. Included in the survey^{1/} were various physical, chemical, and electrical phenomena adaptable to conversion, as well as several modifications of the conventional distillation process, designed to increase the productivity and reduce the size and cost of the necessary equipment.

Some 30 potential conversion processes, actual and potential, were originally delineated in this survey, although they were ultimately reduced to 16 processes deemed worthy of further study. These, in turn, were segregated into four basic process groups: (1) distillation; (2) membrane processes; (3) freezing; and (4) others. The last group includes such techniques and phenomena as chemical, solvent extraction, and biological processes.

Some important research activities carried on by the Office of Saline Water are outlined in the next section.

Scale and Corrosion

Although there are several different types of distillation equipment and cycles, all are presently subject to the same general limitations due to the deposition of scale and corrosion. Scale forming constituents, principally calcium

^{1/} United States Department of the Interior, "Demineralization of Saline Waters". A compendium of existing and potential separation processes, phenomena, and energy sources with discussion and literature references, October 1952.

carbonate, calcium sulphate, and magnesium hydroxide are precipitated out of solution as evaporator temperatures rise above about 160° F. The scale fouls heat transfer surfaces and impedes fluid circulation. In addition, brines become more corrosive, necessitating use of expensive alloys as temperatures approach or exceed the normal boiling point of water (212° F. at sea level). Battelle Memorial Institute is making a survey of materials of construction suitable for use in conversion plants.

A series of research and development studies has been in progress by the Office of Saline Water in the fields of heat transfer, scale prevention, and cost reduction for corrosion resistant materials. Some of these studies are co-sponsored by other government agencies while additional investigations are being conducted by independent manufacturers in the United States and elsewhere, and by agencies of other foreign governments, such as the British Admiralty.

Formation of scale deposits in evaporating equipment is a serious problem in practically all distillation processes, and under certain conditions it is also a problem in electro-dialysis. A fundamental investigation of the basic factors affecting scale deposition is being conducted at the University of Michigan Research Institute under contract to the Office of Saline Water.

Long-Tube Vertical Distillation

A distillation process, seemingly attractive economically and using long-tube vertical evaporators of the kind

employed in the pulp industry, was proposed by Dr. W. L. Badger. In this technique, sea water is passed through a series of evaporators under reduced pressure and temperature, utilizing heat either applied directly from a steam generator or recovered from the exhaust of a steam turbine in connection with electric power generators. A pilot plant has been erected at Wrightsville Beach in North Carolina and tests have been made on scale prevention, metal corrosion, and heat transfer rates, all of which have an important influence on the performance of a distillation plant.

Rotating Still

Improved evaporators, in which greatly increased rates of heat transfer are achieved, give promise of reducing capital as well as operating costs. In one such development, the heat transfer coefficient is greatly increased over that obtained with conventional equipment. In this process, invented by Dr. Kenneth C. D. Hickman of Rochester, New York, the heat transfer area is in the shape of conical surfaces and is rotated, thereby causing the feed water to spread over the surfaces in thin films, under the action of centrifugal force. Several experimental models have been constructed ranging in size from household sizes (300 gallons per day) to much larger units (25,000 gallons per day). These are being tested on brackish, as well as on sea waters.

Dropwise Condensation Heat Transfer

Another heat transfer system is under development by Drs. B. F. Dodge and A. M. Eshaya of New Haven, Connecticut.

Tests were run on laboratory equipment at Yale University which demonstrated that high heat transfer coefficients could be maintained in a system utilizing forced circulation and dropwise condensation (condensation in the form of droplets on the condensing surface) in vapor compression distillation processes. Similar and complementary research was conducted by the British Admiralty under the European Cooperation Program. Several private organizations in the United States and Europe are experimenting with dropwise promoters for various types of heat exchanger surfaces.

Low Temperature Difference Flash Distillation

For locations where waste heat is available or where ocean temperature differences are sufficient to induce flash evaporation, this process may prove to be feasible. This problem was recently studied by Griscom-Russell Company, Massillon, Ohio, for the Office of Saline Water, using the energy of a stream of warm waste water from the power station of an industrial plant, or warm water from natural sources. Estimates indicate that, with a temperature difference of 30° F. between the warm and cold water, plants of 100,000 and 10,000,000 gallons per day output capacity would produce fresh water from sea water at overall costs of \$1.75 and \$1.20 per 1,000 gallons, respectively.

Solar Still

Research on solar stills, with the objective of reducing cost of equipment and increasing efficiency is being carried out by the Office of Saline Water and other associated

groups, such as the University of California and the University of Florida. Both glass and plastic membranes have found application as transparent covers for solar stills, and equipment costs are being reduced.

The Office of Saline Water has initiated a comprehensive development program on solar stills through contract with Battelle Memorial Institute of Columbus, Ohio. Prototypes of various existing and improved designs have been installed and are being tested at a seashore test station near Port Orange, Florida.

The Office of Saline Water expects that the Solar Distillation Center, in Florida, will produce engineering designs and specifications for practical future solar distillation plants.

Membrane Research for Electrodialysis and Osmosis

Conversion processes utilizing membranes have been developed during the past few years to the point where several are known to be technically feasible. One process, electrodialysis, also appears to be economically feasible for the treatment of brackish water under certain conditions.

Specifically, the membrane processes showing promise are (1) electrodialysis, where an electromotive force is applied to a cell consisting of ion selective membranes, (2) "osmionic", where the concentration gradient between the solution supplies the potential to drive ions through ion selective membranes, and (3) reverse osmosis, where sufficient pressure is applied to the solution to force water through an ion restraining membrane into the fresh water side.

One of the limiting factors in the use of these processes has been the membranes themselves. During the past few years, considerable research has been conducted by the Office of Saline Water and by organizations in several countries aimed at improving the characteristics of those membranes. As a result, greatly improved ion selective membranes have been developed. Such membranes are now available commercially at a cost per unit area of approximately one-fifth the former cost.

One of the leading American firms engaged in development and manufacture of electrodialysis equipment is Ionics, Inc. This firm, following extensive laboratory development, built a saline water conversion pilot plant mounted in a trailer truck, and operated it for an extended period in Arizona and South Dakota, using two naturally occurring saline waters with salinities of 4,000 parts per million and 2,000 parts per million, respectively.

The Office of Saline Water is conducting membrane evaluation and improved cell development at the laboratories of the Bureau of Reclamation in Denver, Colorado. Membranes prepared by foreign as well as by American manufacturers are under test.

The second membrane process named above is termed "osmionic", a word coined to include both the osmotic and ionic forces involved in the process. This is one of the new processes developed under the Office of Saline Water program and is somewhat similar to electrodialysis, except that it requires no outside source of electrical power and no electrodes. The activating force is obtained from the difference in concentration

between a brine and the water to be demineralized. The power supply, therefore, might be obtained from salt deposits, brine wells, or by ponding saline water and allowing the sun to concentrate the water.

Reverse osmosis involves the passage of water through a membrane from a concentrated solution to a more dilute one. If enough pressure is applied to the more concentrated solution (more than 370 pounds per square inch pressure for sea water), the osmotic flow can be reversed and pure water will be forced through the membrane. This technique is known as reverse osmosis. Results of research sponsored by the Office of Saline Water have demonstrated that around 97 percent of the salts of sea water can be removed in one pass through a membrane, such as cellulose acetate, at a slow rate of flow. Investigation aimed at increasing the durability and flow rate of membranes is continuing.

Freezing Process

A promising approach to the utilization of freezing as a means of saline water conversion and elimination of the brine from the crystals is a combination of freezing and evaporation being investigated by the Carrier Corporation, Syracuse, New York, for the Office of Saline Water. Experimental apparatus and washing techniques have been developed so that it is now possible to continuously produce practically salt-free ice from sea water. In this process chilled saline water is admitted to a chamber under high vacuum. At this low pressure, about one-seventh of the water flashes to vapor,

further chilling the remainder, which freezes to an ice-brine slurry. The slurry then flows through a separation column for counter-current washing. The vapor formed in the freezing operation is compressed and condenses on the ice. The melted ice becomes the fresh water product. Part of the product is in turn used for washing the ice.

The experimental program on this process utilizing a small shop-size pilot plant, has not appeared to disclose any technical problems that would render the process impractical. Operation of the equipment is continuing and a larger pilot plant of about 15,000 gallons per day of fresh water has been constructed and is being tested.

In another approach to the use of freezing for demineralizing saline water an immiscible refrigerant, such as isobutane, is vaporized in direct contact with the saline solution. The development of this principle is being studied at Cornell University, Ithaca, New York, for the Office of Saline Water. A pilot plant is being constructed at St. Petersburg, Florida, by Blaw Knox Company as a continuation of this program. Because most equipment necessary for this process could be of comparatively simple design, it may be adaptable to large-scale installations.

Ion Exchange

The phenomenon of ion exchange was first investigated about 1850, but it is only within the past 20 years that this principle has been extensively developed commercially for treating water of low salinity and for removal of hardness.

Salt ions can be removed from saline water by passing the water through a bed of ion exchange material. The exchange material soon becomes saturated and must be regenerated by use of relatively expensive acids and bases. Among efforts directed toward reduction of regeneration costs was some experimentation at the University of California in which ammonium bicarbonate was used as a regenerant. When saline water is passed through such a bed, it is demineralized and the effluent consists of water containing only ammonium bicarbonate. Heating the solution removes the chemical as carbon dioxide and ammonia gases which are collected and used again to regenerate the exchange resins in the bed. Thus, the costly chemicals used for regeneration are replaced by the action of heat. However, the amount of heat required to operate this process approaches that required for a distillation process. The process, though technically feasible, is too expensive to be practical, and research is now being directed toward partially softening sea water by demineralization as a pretreatment for the feed water to a distillation plant.

Organic Solvent

The extraction of water from saline solution by an organic solvent, to be recovered later from the extracted mixture of water and solvent, by temperature change, has been found sufficiently promising for further research. The process is under development by Texas Agricultural and Mechanical Research Foundation, College Station, Texas, for the Office of Saline Water. Satisfactory laboratory equipment has indicated the desirability of the initiation of pilot plant development.

Application to Nuclear Energy

Due to the high cost of nuclear energy, it was originally felt that this energy source would probably not play an early role in saline water conversion. However, in 1957, the Office of Saline Water sponsored a study by the Fluor Corporation of Whittier, California, of the possible use of low temperature nuclear heat in a distillation conversion process. The results were encouraging and the Office of Saline Water, in cooperation with the State of California, thereupon engaged the Fluor Corporation to make a design study of a 50 million-gallon-per-day multistage flash distillation plant with steam supplied by a nuclear reactor. The reactor selected was a pressurized water type of 370 thermal megawatt capacity. With an assumed 25-year plant life and 345 operating days per year, the estimated water cost was \$0.42 per thousand gallons.

Demonstration Sea Water Conversion Plants

The passage of Public Law 85-883, by the 85th Congress, on September 2, 1958, authorized the construction of five demonstration conversion plants, three for sea water and two for brackish water, to be placed at various advantageous locations throughout the country. The objective of this program was the advancement of the techniques of saline water conversion by the construction of a number of demonstration plants, of several types, in order to determine the engineering and economic potential of the selected demineralization processes. The demonstration program contains an authorization of \$10,000,000 for the purpose of constructing the five plants.

Long-Tube Vertical Distillation Plant--Texas

The initial installation to be built under Public Law 85-883 will produce 1,000,000 gallons per day of fresh water and will be built at Freeport, Texas. The plant will be a 12-effect long-tube vertical distillation type, similar to those used in the pulp industry for concentration of spent sulfite liquor. The construction contract for \$1,246,250 was awarded to Chicago Bridge and Iron Company in June 1960. Ground-breaking ceremonies were held in September 1960. The contract calls for construction and start-up operations to be completed within 330 days.

Multistage Flash Evaporation Plant--California

The second demonstration plant to be built under the program is a multistage flash evaporation type of 1,000,000 gallons per day capacity. The construction contract for this plant, in the amount of \$1,608,000, was awarded to Westinghouse Electric Corporation in November 1960. The California Department of Water Resources assisted in the site selection for the plant and conducted a detailed survey of 18 proposed coastal locations from San Francisco to San Diego. The principal criteria used in evaluating the various sites reflected technical and economic requirements associated with both the type of plant and the impact on the locality. The evaluation data and recommendations were forwarded to the Director, Office of Saline Water, who made the final choice with the assistance of a three-man site selection board. The announcement of selection of the Point Loma site in San Diego was made by Secretary of the Interior Seaton on October 6, 1959.

The Fluor Corporation of Los Angeles was awarded a contract by the Office of Saline Water for the final design and specification of the distillation plant. This design was based on a preliminary design study performed by the same firm, the cost of which was shared by the Federal Government and the State of California. The State will also share equally with the Federal Government in the cost of the final design and construction.

The State's collaboration in the demonstration plant program will provide useful knowledge for the design, construction, and operation of this type of sea water distillation plant. The California Department of Water Resources will likewise maintain active liaison with the technical programs of the demonstration plants located in other states.

Electrodialysis Plant--South Dakota

The third demonstration plant to be constructed under Public Law 85-883 is to be of the electrodialysis type and will be used to convert brackish to fresh water. It will be located at Webster, South Dakota, and will have a fresh water capacity of 250,000 gallons per day. A contract for design and construction of this plant, in the amount of \$482,200, was awarded to Asahi Chemical Industries Company of Japan in cooperation with the Austin Company of Cleveland Ohio, in November 1960.

Vapor Compression Distillation Plant--New Mexico

The fourth demonstration plant to be constructed under Public Law 85-883 is to employ the forced-circulation

vapor compression distillation process, and will convert brackish water to fresh water at a rate of 250,000 to 1,000,000 gallons per day. The plant is to be located at Roswell, New Mexico.

Freezing Process Plant--North Carolina

The fifth process to be used in the demonstration plant program will use the freezing method. The type of freezing process has not been announced (December 1960), but the location of the plant is Wrightsville Beach, North Carolina.

Cost Estimates for Sea Water Conversion

Unfortunately, although the aggregate capacity of conversion plants throughout the world amounts to many million gallons per day, very little information is available on water costs based on actual plant operation. The fact that most of the large distillation plants are located overseas adds to the difficulty of securing cost data and even those obtained cannot be readily applied to United States conditions because of differences in labor, material, and fuel costs. Therefore, at the present time we are largely dependent upon engineering estimates for conversion costs and it must be recognized that these can never be as reliable as costs established by several years of operation of full-size plants. One valuable result of the federal conversion plant program will be the determination of accurate costs of production of medium-size plants under United States conditions.

In order that all pertinent physical factors would be given consideration, and to secure uniformity in estimating plant capital, energy, and maintenance and operation costs, the Office of Saline Water, in March 1956, issued a bulletin, entitled "A Standardized Procedure for Estimating Costs of Saline Water Conversion". Typical factors in the standardized cost computation procedure include the following:

<u>Item</u>	<u>Factor</u>
Land	\$3 per 1,000 gallons of daily plant capacity
Electrical energy	5 to 7 mills per kilowatt-hour (depending on power demand)
Fuel	25¢ per million Btu
Steam	55¢ per 1,000 pounds
Plant life (general)	20 years at 4% interest
Amortization rate	7.4% per annum (capital recovery)
Product water shortage	Provide for storage of 10 days production

Most investigators and manufacturers have made a conscientious effort to conform to the above criteria in the preparation of estimates of costs for saline water conversion processes.

Estimated Present Costs of Converted Saline Water

A comparison of total water costs, based both on estimates and on operation of existing sea water and brackish water conversion facilities is given in Table 10. These costs vary from \$0.63 to \$3.00 per thousand gallons (\$205 to \$977 per acre-foot).

TABLE 10

COSTS OF CONVERTED WATER BASED ON
THE OPERATION OF EXISTING PLANTS

Process	: Plant : location	: Plant : capacity, in : gallons per day	: Type of: : water : : treated:	Cost of water per 1,000 gallons
Multiple-effect Distillation	Aruba	2,700,000	Sea	1.75 ^{1/}
Multistage flash Distillation	Kuwait	2,400,000	Sea	0.63 to 1.87 ^{2/}
Vapor Compression Distillation	--	100,000	Sea	1.85 to 3.00 ^{3/}
Multiple-effect Distillation	Morro Bay, California	150,000	Sea.	2.50 ^{4/}
Electrodialysis	Coalinga, California	28,000	Brack- ish (2,000 ppm).	1.45 ^{5/}

- 1/ Sonderman, G. E., Consulting Engineer, February 1958. This is a combination water and power plant. Cost of water is somewhat less if allowance is made for the sale of power.
- 2/ Hearings before the Subcommittee on Irrigation and Reclamation of the Committee on Interior and Insular Affairs, United States Senate, 85th Congress, second session on S. J. Resolution 135 and S. 3370, March 20 and 21, 1958, p. 133.
- 3/ Union Calendar No. 1069, House Report No. 2551, 85th Congress, second session, Saline Water Program, thirty-first report by the committee on Government operations, August 13, 1958, p. 20. (Plant location not given)
- 4/ Bruce, A. W., "Five Year Experience Making Fresh Water from Sea Water at Morro Bay Power Plant, Colloquium on Desalting Water Held at California Institute of Technology", May 5 and 6, 1960.
- 5/ "City Orders Saline Water Plant", Engineering News-Record, June 5, 1958.

The plant at Aruba, Netherlands West Indies, is a good example of a modern sea water conversion plant of the multiple-effect type, for which some operating experience has been gained. The Aruba plant is designed to produce 2.7 million gallons of distilled water daily. In addition, it can generate

12,500 kilowatts of electrical energy from 15,000 kilowatts installed capacity. The capital cost of this plant is estimated to be \$10.6 million. The capital cost per daily gallon of installed water capacity at Aruba is, therefore, approximately \$4. However, the electrical generating equipment represents a substantial part of the total investment and if it were not required, \$3 to \$3.50 per daily gallon of water capacity would be a reasonable estimate of the capital investment for the water and steam plants alone. As is shown in Table 10, the resulting total water cost is estimated to be \$1.75 per 1,000 gallons or \$570 per acre-foot without allowance for the sale of power. If power were sold at normal wholesale rates and profits applied to the cost of water, the water cost might drop to about \$1.25 per thousand gallons^{1/}.

At the request of the Department of Water Resources, several manufacturers of distillation-type sea water conversion plants were requested to submit estimates of total water costs involved in the use of their equipment. The returns from this survey are shown in Table 11. Estimates varied from \$0.60 to \$1.15 per 1,000 gallons or from about \$196 to \$375 per acre-foot. The fresh water plant capacities range from 100,000 to 10,000,000 gallons per day, the unit costs being least for the largest plant.

^{1/} Sonderman, G. E., "Sea Water Distillation With By-Product Power at Aruba", presented at semi-annual convention of ASME, June 1959.

TABLE 11

ESTIMATED COSTS OF DISTILLATION-TYPE SEA WATER
CONVERSION PLANTS OF VARIOUS CAPACITIES^{1/}(Manufacturers' estimates based on Office of Saline Water
standard procedures for estimating costs)

Manufacturer	Plant capacity, in gallons per day of fresh water	Total capital cost, in dollars	Capital cost per gallon per day of production, in dollars	Total water cost, in dollars per 1,000 gallons ^{2/}
A	2,500,000 10,000,000	2,400,000 8,800,000	0.96 0.88	0.80 0.60
B	1,180,000 1,180,000	1,766,000 ^{3/} 1,537,000	1.50 1.30	1.02 0.89
C	100,000 600,000 6,000,000	241,000 1,175,000 10,600,000	2.41 1.96 1.77	1.15 0.94 0.88

^{1/} Received October 1958, in response to requests by the California Department of Water Resources.^{2/} Multiply dollars per 1,000 gallons by 326 to get dollars per acre-foot.^{3/} Includes 5,500 kilowatts of power generation facilities.

Estimates of costs prepared by the Office of Saline Water for the authorized demonstration plant program are presented in Table 12. It is hoped that these costs may be reduced when the demonstration plants become operational and actual cost figures will be available.

Table 13 shows how the cost of product water increases as the salinity increases for the electrodialysis process. The number of applications of this process to areas of brackish water in California may well increase as this process is refined and normal water costs continue to rise.

Predicted Future Cost of Converted Saline Water

Information on costs and performance of operating plants is meager, as discussed above. However, based upon the few available cost data on existing plants together with various engineering studies performed it is estimated that a plant of reasonable size, say 10,000,000 gallons per day capacity, could be built today to produce water for about \$0.75 per thousand gallons. With future improvements in equipment and with lower cost energy sources that may develop, such as nuclear, costs of converted water in the foreseeable future may approach \$0.50 per thousand gallons.

Rapid advances are being made in the development of reliable and efficient membranes for the electrodialysis technique of treating brackish water, and it is reasonable to expect conversion costs in the future to be considerably reduced from those obtained at the present time. One authority predicts that brackish water having a dissolved solids content

TABLE 12

ESTIMATED COSTS OF DEMONSTRATION CONVERSION PLANTS

(Authorized by Public Law 85-883)

Process and location	Plant capacity, : in gallons : per day of : fresh water	Capital cost, : in dollars per : gallon of : daily capacity:	Water cost, : in dollars per : thousand gallons
Long-tube vertical evaporator - Freeport, Texas	1,000,000	1.25 ¹ / ₂	1.00 ³ / ₄
Multistage flash evaporation - Point Loma, San Diego, California	1,000,000	1.61 ⁴ / ₄	1.10 to 1.20 ⁵ / ₄
Electrodialysis ⁶ / ₄ - Webster, South Dakota	250,000	1.79 ⁷ / ₄	1.14 ⁷ / ₄
Forced-circulation ⁸ / ₄ vapor compression - Roswell, New Mexico	250,000 - 1,000,000	-----	-----
Freezing ⁹ / ₄	100,000 - 350,000	-----	-----

¹/ Low bid, Office of Saline Water News Release, June 8, 1960.²/ Not including boiler and sea water submarine pipeline intake.³/ Office of Saline Water News Release, March 2, 1959.⁴/ Low bid, Office of Saline Water Specifications No. 198 (including boiler and submarine line).⁵/ Office of Saline Water Research and Development Report No. 34.⁶/ Reduce 1,800 parts per million brackish water to a product water of 500 parts per million.⁷/ Low bid on Office of Saline Water Specification No. 212.⁸/ Architect-engineer contract awarded to Catalytic Construction Company, October 1960, for design of plant.⁹/ The exact process has not been selected (January 1961).

TABLE 13

REPRESENTATIVE ESTIMATES OF PRESENT
BRACKISH WATER CONVERSION COSTS BY ELECTRODIALYSIS PROCESS^{1/}

Source :	Plant capacity, :	Cost, in :	Reference
salinity, :gallons per day:	parts per million :	parts per million :	
of fresh water:	of fresh water:	of fresh water:	
1,670	500,000	0.50 to 0.55	Statements of E. R. Gilliland and W. Juda at Hearings before the subcommittee on Irrigation and Reclamation of the Committee on Interior and Insular Affairs, U. S. Senate, 85th Congress, Second Session, on S. J. Resolution 135 and S. 3370 (Saline Water Conversion), Washington, D. C., March 20, 21, 1958, pp. 85-97.
1,910	1,000,000	0.56 to 0.62	
1,950	200,000	0.58 to 0.65	
2,400	2,800,000	0.65	
2,000	2,000,000	0.37	Katz, William E., Some Practical 1959 Advances in Electrical Membrane Demineralization, ACS Meeting in Cleveland, April 1960.
4,000	2,000,000	0.58	

^{1/} Product water of about 500 parts per million.

of 4,000 parts per million and 2,000 parts per million will be \$0.50 and \$0.30 per thousand gallons, respectively^{1/}.

No indication exists of a "breakthrough" to greatly reduced conversion costs by any process known today. It may be that some technique entirely unsuspected at the present time may offer the key to really cheap converted saline water.

Summary

During the past decade the means of producing, from sea and brackish sources, water potable to man and usable for agricultural and industrial purposes, has been under intensive investigation in the United States and abroad. Plants to accomplish such demineralization now aggregate, worldwide, a daily capacity of about 24,000,000 gallons of fresh water (see Table 1).

Processes for the conversion of sea water are at the present time largely limited to distillation techniques, such as multistage flash, vapor compression, or multiple-effect submerged coil, all of which produce water at costs several times those associated with normal development of natural water resources. Adding to the normal costs, most distillation plants are plagued with problems of scale formation on heating surfaces exposed to saline water. To this factor alone, 10 to 20 percent of optimum production is lost in many installations. This scaling problem is receiving wide and extensive study by many interested agencies.

^{1/} Gillam, W. Sherman, "The Cost of Converted Water Meeting of American Institute of Mining, Metallurgical and Petroelum Engineers, Inc., New York, February 1960".

The cost of producing potable water from the sea for large plants (10,000,000 to 100,000,000 gallons per day) such as might be utilized at a coastal area of California as of 1960, is not accurately known, due to the very limited worldwide experience with such plants and the fact that none have been built in the United States. It is conservatively estimated, however, that a large distillation conversion plant, constructed at the present time, could produce potable water from sea water at a total cost of about \$0.75 per thousand gallons; within 10 years, the cost could perhaps decline to about \$0.50 per thousand gallons. Lower estimates have been made, but until more experience has been gained with moderate-size plants it is desirable to be reasonably conservative in cost predictions.

Feasible processes for reduction of mineral content of brackish water are today limited in number. At the present time, electrodialysis is the only process that has found widespread application for the conversion of brackish water. It is probable that, to produce water with only 300 parts per million of total dissolved solids, costs by the electrodialysis process will range from about \$0.30 per thousand gallons for 2,000 parts per million source water to about \$0.50 per thousand gallons for 4,000 parts per million source water in the reasonable future. Demineralized water, when used to blend with moderately brackish water in order to improve its quality, may find useful and widespread application. This is a study worthy of more attention.

The federal demonstration plant at Point Loma, San Diego, California, should provide a useful fund of knowledge concerning the design, construction, and operation of a modern distillation plant. It is not expected that the Point Loma facility will produce converted sea water at costs competitive with fresh water resources developed and made available in San Diego by conventional methods.

Further research efforts in lesser known demineralization methods, such as ion exchange, freezing, hydrate, reverse osmosis, and other more esoteric techniques will undoubtedly contribute valuable data pertaining to future water demineralization.

It appears reasonable to assume that a breakthrough to lower total saline conversion costs, if it occurs, will be the result of a vigorous and continuous program of research and development. Such improvement may well involve a process not yet known or envisioned. This will be best accomplished by mutual awareness of the problems to be solved by scientists and engineers and will require their close and continuous coordinated efforts.

CHAPTER III. NUCLEAR ENERGY

Introduction and History

The harnessing of the world's natural resources into useful tools for technical and economic development has been one of history's most significant challenges, outweighed only by man's attempt to live with his fellow human beings. Nuclear energy and its translation into a useful tool is only one facet of this continuous challenge, but the potential of this resource appears so large that many leaders of science and government predict from it a new era of world prosperity and technical development.

The development of nuclear energy has progressed at a rapid rate, primarily through the impetus of World War II and the intense worldwide scientific competition following this war. Perhaps no industry heretofore known has experienced as rapid a growth as that involving the application of nuclear energy to the betterment of mankind. In the United States alone, this growth has been represented by an increase in employment from a handful of research and laboratory workers in 1940 to a level, in 1960, of well over 100,000 people. As one author has proposed, the economic impact of nuclear energy is probably surmounted only by the industrial revolution.

In spite of this unprecedented advancement, the science of the atom is as old as science itself. In fact, early atomic ideas can be traced as far back as Democritus and the ancient Greeks. While the secret of the atom took nearly

2,500 years to completely unfold, the early formation of such fundamental atomic concepts as those proposed by Dalton, Boyle, Avogadro, Mendeleev, Boltzman, Planck, and others, must be recognized.

The complete opening of the field of atomic nuclei study, now called nuclear physics, occurred in the late nineteenth century with work performed by Hertz and Maxwell on electromagnetic radiation, by Roentgen on x-rays, and Becquerel on the natural radioactivity of uranium minerals. Soon after these discoveries, man's conception of the atom took a giant step forward with Bohr's attempt to combine Newton's mechanics with Planck's quantum theory and to arrive at the solar system atom model. This model was later followed by a more sophisticated version through the work of Heisenberg, Schrodinger, Pauli, and others.

In 1905, Albert Einstein introduced his now famous "theory of relativity", a theory which forms the very basis of nuclear energy. With the advent of this concept, interest in nuclear physics reached a new high. Positive identification of atomic structure and the components of the atom was made and a wide variety of new concepts was formulated. Intense laboratory experiments were initiated to further study the atom model.

At first, extreme difficulties were encountered, since tools of the same size as the atom itself were necessary for accurate study. As one scientist phrased the problem, "You can't study the anatomy of a fly with an elephant's foot."

The solution to this problem centered on the so-called particle accelerators, of which one of the most successful was

the cyclotron built by Lawrence and his co-workers at Berkeley, California, in 1931. As a result of these experiments, and others, the uranium-fission reaction was defined and the corresponding energy release was observed. On December 2, 1942, the first sustained nuclear fission chain reaction was achieved under the direction of Enrico Fermi at the University of Chicago. This reaction was created in a graphite uranium "pile", which later served as a pilot for future piles (later called reactors) built at Oak Ridge, Tennessee, and Hanford, Washington. The modern era of nuclear energy, or more popularly called atomic energy, had commenced.

It is necessary to recall only a few of the more recent events of this era to demonstrate nuclear energy's rapid advancement. There was the explosion of the first nuclear test device at Alamogordo, New Mexico, in 1945; the explosion of the first nuclear bomb over Hiroshima, Japan, in 1945; and the testing of thermo-nuclear devices in the South Pacific in the early fifties. There was the launching of the first atomic submarine, the Nautilus, in 1954; the start-up, in 1957, of the first full-size United States civilian power reactor at Shippingport, Pennsylvania; and more recently, the launching of the first nuclear-powered merchant ship, the Savannah. There was also a host of developments in the use of by-product radioactive isotopes in such diverse fields as medical research, materials testing, agriculture, and water supply. While these are only a few of the many milestones which have occurred during the last two decades, their significance is obvious and their effects may be felt for centuries.

In spite of the public's awareness of these many advances and in spite of our leaders' optimistic predictions of the worldwide benefits to be obtained from nuclear energy, one might still question the need for development of this resource and more specifically its potential applications to the California Water Plan. Even by recognizing that practically all advances in any technical field result from man's attempts to resolve the unknown, and that nuclear energy has further been exploited through its military implications and cold war psychological advantages, the question of benefits to mankind still arises. The answer to this question exists in recent attempts to take inventory of the world's fossil fuel energy resources. While these attempts have led to much conjecture, it has been estimated that the total fossil fuel energy reserves in the world that can be recovered at costs no higher than twice 1950 costs amount to about $270 \frac{1}{10}$ ($10 = 10^{18}$ Btu, equivalent to 40 billion tons of coal). Similarly it has been estimated that man's present use of energy amounts to approximately 0.10 per year. Thus, with no increase in the rate of consumption the world's fossil energy reserves would be sufficient for about 270 years.

However, the world's population is increasing rapidly, and with this increase the standard of living is progressing at an accelerated rate. Consequently, any attempt to extrapolate today's rate of energy consumption into the distant future must allow for a continuing annual increase. A logical approach was presented in a paper by Professor E. S. Mason, of Harvard 1/"Energy in the Future", by Palmer Cosslett Putnam

University, at the 1955 Geneva Conference on Peaceful Uses of Nuclear Energy. In this paper Mason suggests that an annual rate of increase in world energy consumption of three to four percent per year is probable, a rate which results in the doubling of energy consumption by about the year 1980, and a threefold to fivefold increase by the year 2000. By assuming that this rate of increase is representative, the world's fossil fuel energy resources will be depleted in about 100 years.

While the present analysis does not necessarily forecast a worldwide shortage of energy reserves, and while it is true that new reserves will be discovered and new processes invented to economically mine less attractive fossil energy resources, the picture is clear that the addition of a new energy resource is a necessity to man's continued progress. When applied to specific countries this necessity becomes even more evident, considering that many of these countries import their fossil fuels from vast distances. This condition is particularly true in the Western European countries whose complete industrial economy depends heavily upon these imports.

The situation was ably emphasized in February 1955 in the so-called British "White Paper", entitled "A Programme of Nuclear Power", presented to the British Parliament by the Lord President of the Council and the Minister of Fuel and Power. This paper concluded that:

"Our civilization is based on power; improved living standards, both in advanced industrial countries like our own and in the vast underdeveloped countries overseas, can only come about through the increased

use of power. The rate of increase required is so great that it will tax the existing resources of energy to the utmost. Whatever the immediate uncertainties, nuclear energy will in time be capable of producing power economically. Moreover, it provides a source of energy potentially much greater than exists now. The coming of nuclear power marks the beginning of a new era."

To illustrate how nuclear energy may assist those countries such as Great Britain in their continued economic growth, several comparisons may be made. Of primary significance is the fact that many of those countries lacking mineral fuel resources have a large abundance of nuclear fuel resources. Obviously the development of economic nuclear power would assist considerably in the growth of these countries. But even those countries with neither nuclear nor mineral fuel resources may gain a considerable advantage from the development of nuclear power, since the useful energy content per unit weight of nuclear fuels is practically a million times that of coal. The economic advantage in transporting nuclear fuels rather than fossil fuels would be considerable.

But perhaps the most significant advantage rests in the availability of future nuclear energy reserves. While no firm estimates of this availability exist, the known reserves of uranium ore amount to a two or three hundred years' energy supply; those of thorium ore appear even larger; and the supplies of deuterium or "heavy hydrogen", the isotope forming the basis of the fusion reaction, are almost unlimited.

While the above arguments illustrate the potential advantages to the world of developing a new energy resource, they are not necessarily pertinent to the California Water Plan.

However, California's fossil fuel resources are dwindling rapidly and a large part of its requirements are met through importations. It is likely that fossil fuel prices will continue to rise though the costs are already high enough to make the advantages of a cheaper energy source readily apparent.

Today, nuclear energy cannot compete in California with fossil fuel energy, but many authorities foresee the day (perhaps as early as the 1970's) when nuclear energy will offer definite economic advantages to every section of the State.

In view of the huge pumping power requirements of the California Aqueduct, it is prudent that a close watch be kept upon developments in the nuclear field, in hopes that it will offer specific cost advantages in the proposed State Water Resources Development System, and also to aid us in being prepared to take advantage of these favorable costs when and if they should occur.

However, not only may nuclear energy be of primary importance for pumping in the State Water Resources Development System, but it may gain increasing importance as an energy source for saline water demineralization. As was indicated in Chapter II, while no known sea water conversion process is presently competitive with the large-scale development and conveyance of natural fresh water resources in the State, it is probable that sea water conversion will gain increased use in many arid regions of the world. The definite process techniques through which this increased utility may occur are not

definable, but whatever their nature the energy requirements will be considerable. As such, nuclear energy may be a significant contributor to these requirements, not only because of its previously mentioned advantages, but because of the fact that a nuclear heat energy system has certain economic advantages when applied to a distillation process, the most widely used conversion technique employed today.

Fundamentals of Nuclear Energy

While this bulletin is not intended to be a theoretical explanation of the field of nuclear energy, the understanding of certain fundamental nuclear concepts and terminology is necessary for complete comprehension of material presented elsewhere in the report. This section will attempt to present these concepts.

The Atom

The basic constituent of all matter is the atom; hence, the terminology of atomic physics, atom bomb, atomic power, etc. However, the atom itself is composed of several subatomic particles, the arrangement and quantity of which determine the basic physical and chemical properties of the specific atom.

The primary subatomic particles involved in atomic structure are the electron, proton, and neutron. The arrangement of these particles is often represented by the solar system atom model, in which particles of small mass rotate in orbits at a relatively large distance and velocity about a central particle or concentrated group of particles of large mass as shown in Figure 16.

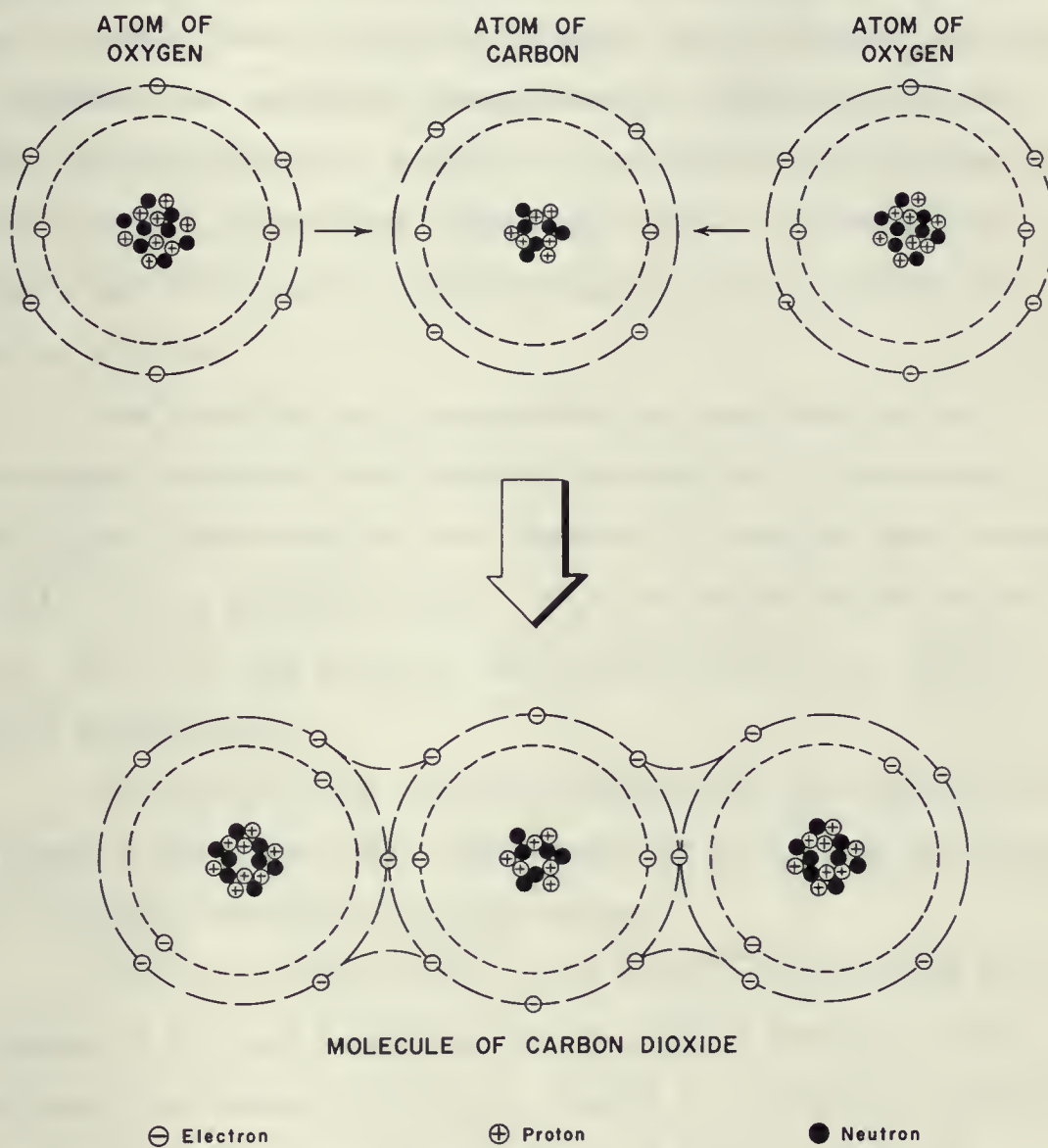


Figure 16

ATOM AND MOLECULE MODEL

The outer particles of this model are electrons, while the central mass, called the nucleus, is composed of protons and neutrons. Electrons carry a negative electric charge, protons carry a positive charge, and neutrons, as their name implies, are neutral. Consequently, there must be an orbital electron for each proton in the nucleus for an atom to be electrically neutral and therefore stable. An atom containing a specific number of electrons and thus protons, is called an element.

The quantity and arrangement of electrons in the outer orbits determine the chemical properties of the atom. Since nuclear reactions are not chemical in nature, this arrangement will not be discussed here. The structure of the inner part of the atom, the nucleus, determines most of the atom's physical properties.

To classify the various arrangements and quantities of subatomic particles, two number systems have been formulated, that of atomic number and of mass number.

The atomic number (Z) of an atom is equivalent to the number of protons contained in the atom's nucleus. To illustrate, the element of atomic number 1, hydrogen, contains one proton in the nucleus, while that of atomic number 92, uranium, contains 92 protons in the nucleus. Recalling that for each proton in the nucleus there exists an orbital electron, and the number of orbital electrons determines the chemical properties of an element, it can be realized that the atomic number indirectly signifies an atom's chemical properties.

The mass number (A) of an atom is equivalent to the number of protons and neutrons contained in the atom's nucleus. Thus, an atom with a mass number of 5 contains a total of five protons and neutrons, and one of a mass number 235, contains a total of 235 protons and neutrons. By knowing the atomic number (Z) and mass number (A) of an atom, it is easy to determine the number of neutrons (N) in the atom's nucleus since $N = A - Z$.

Isotopes

It is interesting to note that by definition of an element, any change in the number of protons in the nucleus would mean the creation of a different element. For instance, if we added one proton to the nucleus of an atom of uranium, atomic number 92, we would have an atom of atomic number 93 called neptunium. On the other hand, if we added three neutrons to an atom of uranium, of mass number 235, we would still have an atom of uranium, but with mass number 238. The atoms of an element having different mass numbers are called isotopes, and these isotopes are usually expressed by abbreviations similar to U-235 (a uranium atom with a mass number of 235), or U-238 (a uranium atom with a mass number of 238).

It is possible to have many different isotopes of a given element. Certain isotopes are stable while others can exist only for very short periods of time. The reason for this is that the combinations of forces within the atom's nucleus allows only certain proton-neutron combinations. Any attempt to alter these combinations by adding neutrons places the nucleus in an excited and unstable state. Once this

excited state is reached, the atom may exhibit any one of several physical properties. The usual event is for the atom to emit some sort of atomic radiation in the form of alpha, beta, or gamma rays. These radiations are a result of the decomposition of one or more of the nucleus particles. In the course of this decomposition, the atom will usually become a more stable isotope of the same element or of a different element. The length of time for this decomposition to occur is expressed in terms of half-lives, which is the time required for half of a given mass of an element to decay into a secondary isotope. Half-lives vary from a few millionths of a second to millions of years.

Because atomic radiations can be measured with appropriate instruments, the use of radioactive isotopes has gained increasing prominence in a wide variety of scientific fields. Indication of actual and possible uses of isotopes by the Department of Water Resources is presented in the section entitled "Isotope Applications".

Fission

A second possibility of the excited nucleus is its disintegration into many subatomic particles and secondary isotopes of varying mass and atomic number. This event is termed "fission". Of nearly 250 naturally occurring isotopes found in the earth's surface, only one, uranium-235, will undergo fission. However, the isotopes thorium-232 and uranium-238, both of which are found in abundance, may absorb neutrons to become the radioactive isotopes, thorium-233 and

uranium-239. These isotopes in turn will decay into the fissionable species, uranium-233 and plutonium-239.

In the course of fission some of the mass of the original atom is converted into energy in accordance with Einstein's famous mass-energy equation, $E = mc^2$, which states that mass can be transformed into energy. In addition, neutrons are emitted, thus enabling the fission to progress into a chain reaction. For instance, in the fission of uranium-235 between two and three neutrons on the average are emitted, thereby making possible two to three second generation fissions for each original fission. This is exactly what happens in an atomic fission bomb, a rapidly diverging fission-chain reaction occurring almost instantaneously with a corresponding large release of energy as illustrated in Figure 17.

Fusion

One phenomenon of nuclear energy is fission; but atomic theory shows us that there is another source of nuclear energy called fusion. Fusion is the combination of atoms of one element into stable isotopes of another element.

To illustrate, hydrogen, atomic number 1, is known to have three isotopes of mass numbers 1, 2, and 3. The isotope with mass number 2 is called deuterium or "heavy hydrogen", and is found in practically every source of water. It contains one proton and one neutron in its nucleus. The isotope with mass number 3, containing one proton and two neutrons, is called tritium. Helium, atomic number 2, has a mass number of 4, thus having two protons and two neutrons in its nucleus.

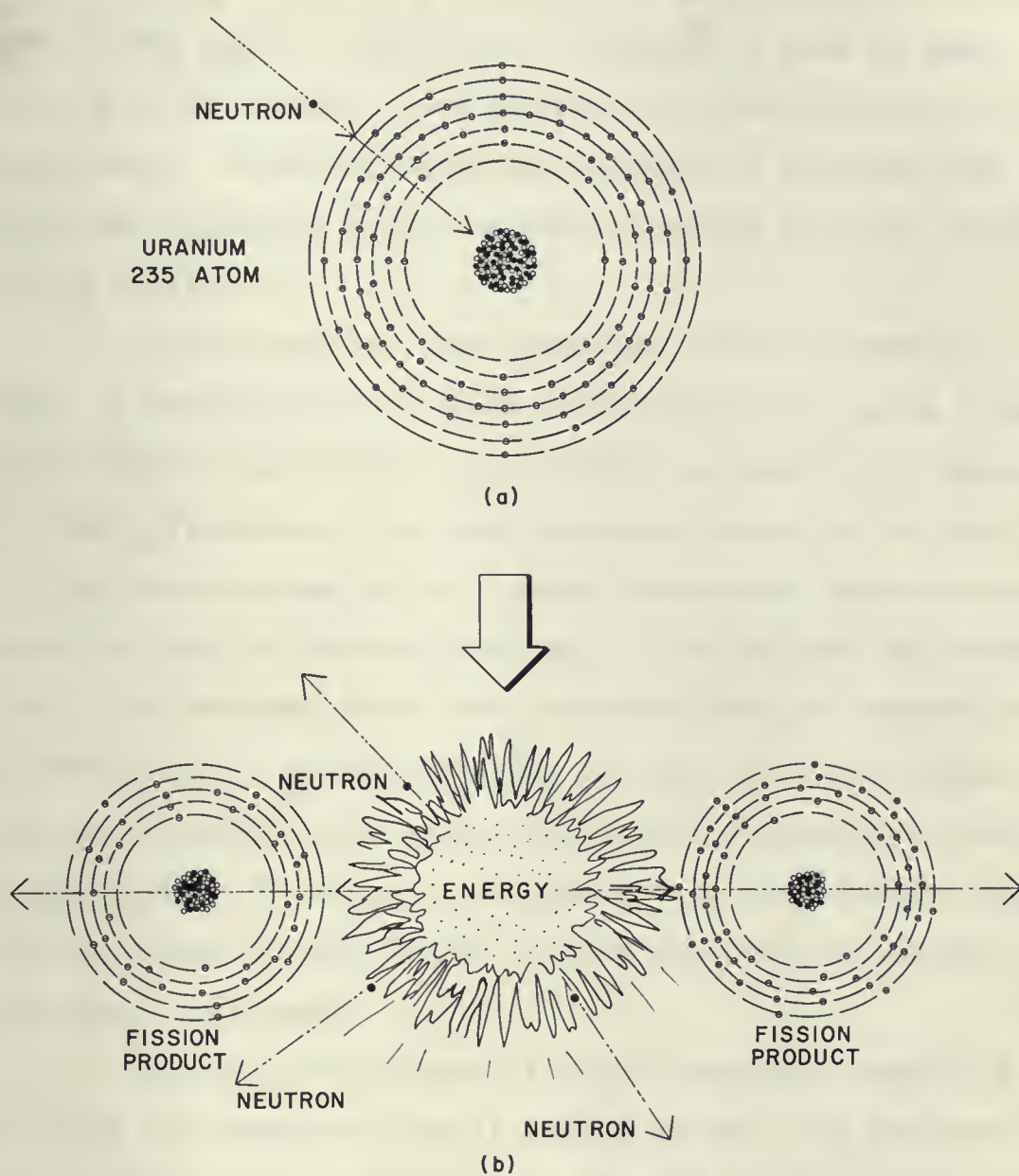


Figure 17

FISSION-CHAIN REACTION

Theoretically, it should be possible to fuse two atoms of deuterium into one atom of helium. If this could be done, a large energy release would occur because the mass of one helium atom is somewhat less than that of two deuterium atoms. Other fusion reactions involving isotopes of hydrogen and helium and releasing large amounts of energy are also theoretically possible.

Unfortunately, there are many forces preventing fusion of hydrogen atoms, since hydrogen physically is a very stable element and offers considerable resistance to change in its atomic structure. The only apparent means to overcome this resistance seems to be through ultra-high temperatures, perhaps as high as several hundred million degrees Fahrenheit. While it is presumed that these temperatures are reached in the detonation of fusion bombs by the explosion of fission devices, the analogy is hardly applicable to peaceful uses of fusion energy. To date, all attempts to create fusion energy in the laboratory have failed and the prospect for success seems many years away.

Because of the many difficult problems remaining to be solved for practical use of fusion energy, our interest in this bulletin will be confined to fission energy. Nevertheless, it should be recognized that fusion represents a tremendous energy source, and may eventually become a most important factor in supplying energy to meet the world's needs.

Relative amounts of energy released from various types of reactions involving one pound of various materials, as compared to coal, are shown in Table 14.

TABLE 14

RELATIVE QUANTITIES OF ENERGY
CONTAINED IN ONE POUND OF VARIOUS MATERIALS

Material	:	Energy
Combustion of coal		12,000 Btu (average)
Combustion of oil		18,000 Btu = 1.5 lbs of coal
Fission of uranium		3.3×10^{10} Btu = 1,375 tons of coal
Fusion, deuterium to helium-3		4.6×10^{10} Btu = 1,900 tons of coal
Fusion, tritium to helium-4		1.8×10^{11} Btu = 7,500 tons of coal
Fusion, hydrogen to helium-4		2.8×10^{11} Btu = 11,500 tons of coal
Annihilation of any matter		3.9×10^{13} Btu = 1,600,000 tons of coal

Nuclear Reactor Concepts

Nuclear energy will not directly operate electric lights, propel ships, or convert sea water to fresh water. Instead, energy in the form of either heat, motion, or electricity is required. Heat is the basic energy form derived from nuclear fission and the machine devised for transferring this heat to a circulating fluid, such as water or gas, is called a reactor. A variety of reactor types has been conceived and the purpose of this section will be to explain those reactor concepts which have proven to be practical or appear to be most feasible, and to indicate the inherent advantages and disadvantages of each type.

General Considerations

Many attempts have been made to classify reactor types, but because of the various parameters involved, these attempts have often ended in confusion. Therefore, this discussion will include a description of the parameters and how they are combined in specific reactors, but attempts at classification will be avoided. The parameters to be included are neutron energy, moderator, fuel cycle, coolant, structural material, and method of control.

The energy of neutrons occurring from a nuclear fission reaction varies considerably, either because of the characteristics of the specific reaction or because the neutrons have collided with other particles and have transmitted some of their energy to these particles. A specific reactor is designed to take advantage of only the neutrons with energies within certain ranges, usually categorized as fast, intermediate, and thermal, or slow.

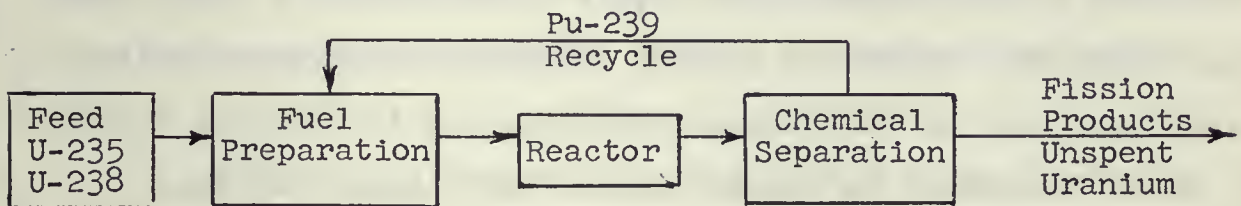
Because reactors are designed for certain neutron energy ranges, it is often necessary to place in the reactor a substance which will slow the neutrons down to the desired level. This substance is called a moderator. Very few substances exhibit ideal moderator properties, since the moderator must only absorb the neutron energy and not the neutron itself. Many substances which exhibit good coolant properties are also good moderators. Since the purpose of moderators is to slow down the neutrons, it is apparent that certain substances can serve the double purpose of coolant and moderator.

The fuel cycle is a most important parameter in reactor concepts, since many of the predicted economic advantages of nuclear energy will occur through the development of unique fuel cycles. In view of the several possible fuel combinations, many reactor concepts with different fuel cycles have been proposed.

It will be recalled that there are three fissionable isotopes, U-235 (uranium), Pu-239 (plutonium), and U-233, of which only U-235 is found naturally. Unfortunately, natural uranium is composed of only 0.71 percent of U-235, the remaining metal being U-238. The process by which U-235 is separated from U-238 is very expensive, thus making the costs of a relatively pure U-235 fuel excessively high. However, it is possible to design a reactor for use of either natural uranium or enriched uranium (uranium in which the concentration of U-235 is increased by varying percentages above the natural concentration). The advantages of natural uranium as a fuel are twofold.

The first advantage is that the original cost of fuel is much lower than that of pure or enriched U-235. The second advantage depends on the fact that U-238 is a fertile isotope (fertile means that the isotope may be converted to a fissionable specie) since the U-238 atoms will absorb some of the neutrons created in the U-235 fission reaction and be converted to Pu-239 atoms, which are fissionable. The second advantage therefore is due to the fact that additional fuel is created, adding to the heat energy that may be extracted from the fuel elements or increasing the amount of fissionable

material that may be obtained (together with unfissioned U-235) by separation from the irradiated fuel removed from the reactor. A similar situation occurs with reactors designed to use U-233 as fuel, with thorium as the fertile material. Diagram of a typical reactor fuel cycle is shown below:



Reactors which generate fuel as they produce power are called "regenerators". There are two special cases of regenerators, designated "breeders" and "converters". In a "breeder" reactor, the consumed and produced species are identical, such as Pu-239 producing new atoms of Pu-239 from U-238. In a "converter" a different species is produced than that consumed, as when Pu-239 is produced from U-238. Regeneration offers the exciting prospect of increasing by manyfold existing supply of fissionable material, as suggested by the fact that natural uranium contains 140 atoms of fertile material (U-238) to each atom of fissionable material (U-235).

As previously mentioned, nuclear energy must be converted to a more useful form, either as heat, motion, or electricity. All presently practical reactor types accomplish this transformation through the steps shown in the following diagram:



The possibilities of converting nuclear energy directly into electric energy, or heat energy directly into electrical, are presently being investigated, but to date no economical scheme has evolved. Therefore, the first step in making use of nuclear energy in a practical machine is to transform it into heat energy. This conversion is a relatively simple process, since the nuclear energy is represented mainly by the velocity of the fission fragments and the slowing down of these fragments, as occurs in the fuel, transforms this energy into heat. The heat is removed by a circulating fluid, either liquid or gas, which flows through the reactor and thence through a heat exchanger for the generation of steam, or, as in the boiling water type of reactor, directly to a turbine. In either case, the heat energy in the steam is converted to mechanical power in the turbine, which in turn drives a generator for further conversion to electrical energy.

Structural materials are very important in nuclear reactor technology. In fact, nuclear reactors have required the development of a wide variety of new structural metals and alloys. For instance, the fuel element cladding (in some reactor types the fuel is in rod or plate form and must be encased for protection) and the reactor core structure must not only offer unique structural properties, but they must also be corrosion resistant and must be resistant to the absorption of neutrons. On the other hand, the reactor shielding and control materials must have the ability to absorb the various types of nuclear radiations.

The method of control is likewise a very important factor in a reactor since obviously it must be possible to vary or to completely halt the nuclear reactions for load changes, for cases of emergency, or for periodic maintenance and fuel loading. The most common method of control is to insert into or remove from the reactor a nuclear poison (a substance which absorbs neutrons), usually in the form of metal rods.

While these features are only a few of the variables represented in different reactor concepts, they are the most essential. Understanding of the terminology and purpose of each variable allows us to discuss the various reactors more fully.

Pressurized Water Reactor

The reactor type most used today, at least in the United States, is the pressurized water reactor (PWR). This concept has been well proven in submarines and in a commercial power plant (Shippingport Atomic Power Station, Shippingport, Pennsylvania) which has been operating since 1957.

Water is an advantageous substance to use in a reactor since its properties are well known, its cost is negligible, and its nuclear characteristics are favorable. Its main disadvantages are its capacity to dissolve solids and its corrosivity.

In the PWR, water in the liquid state is employed as both a moderator and coolant, and flows in a closed loop through a heat exchanger where a portion of its heat is used

to generate steam for a turbine. To prevent boiling and still obtain the temperatures required for efficient turbine-generators, the reactor is operated at high pressures, in the range of 2,000 pounds per square inch--hence the name pressurized water reactor.

The fuel elements in the PWR are usually enriched uranium rods or plates clad in zirconium or stainless steel, although aluminum has been suggested for low-temperature applications. These elements are arranged in a lattice-type configuration. Similarly, the reactor core is usually made of stainless steel with carbon steel being suggested for possible low-temperature applications. Control is usually maintained through the insertion and withdrawal of boron stainless steel rods, boron being a high neutron absorber.

The advantages of the PWR are its reasonable fuel economy, high conversion ratio, use of relatively cheap water, and the extensive experience gained with it. Disadvantages include the high pressure requirements, the corrosiveness of hot water, the high cost of fuel fabrication, and the need for additional heat exchange equipment for the production of steam.

Boiling Water Reactor

To overcome some of the disadvantages of the PWR, the boiling water reactor (BWR) was conceived and is rapidly being developed. Its characteristics are very similar to the PWR with the exception that boiling is allowed in the core. By allowing boiling, the requirements of higher pressures and additional heat exchange equipment are removed. Hence, the

BWR requires lower capital investment than the pressurized water reactor.

Other advantages of the BWR include the lower corrosiveness of steam. Disadvantages are represented by higher fuel costs, radioactive contamination of the steam turbine, and difficulty in control. A further disadvantage, shared by the PWR, is that present designs do not generate superheated steam, a factor which limits turbine efficiencies. Future designs may alleviate this condition by re-cycling the steam through the center of the reactor core or by other means.

There are certain advantages to the use of heavy water versus light water in both the pressurized and the boiling reactor types and considerable developmental work is being done with heavy water as a coolant and moderator. Heavy water is composed of deuterium (hydrogen isotope of mass number 2), and although its properties as a moderator are not quite as good as light water, its neutron economy is considerably better. Because of this economy, fuel cost savings in heavy water reactors are extremely likely. On the other hand, heavy water, which is produced by separation from normal water, where it exists in the ratio of 160 parts per million, is priced at \$28 per pound by the Atomic Energy Commission. Therefore, a reactor which uses heavy water would require higher capital investment, both in the cost of the heavy water itself and in the necessary refinements in equipment required to prevent leakage.

Of further interest is the fact that the most advanced designs of the PWR allow some boiling within the reactor core,

while those of the BWR tend to restrict boiling. It is extremely possible that these two concepts are pointing toward the same goal and that merely a "water reactor" will evolve.

Organic Moderated Reactor

It has been pointed out that the PWR requires high pressure to prevent boiling, while the BWR presents difficulty in providing superheat. To overcome these problems, it was proposed to use coolants whose boiling points are well above the temperatures required to superheat steam. From these proposals several reactor concepts have evolved.

One of these is the organic moderated reactor (OMR), a reactor type which now is offering economic competition to the water type systems. This reactor uses any of several organic substances, such as diphenyl, as both a moderator and coolant. These substances offer reasonable moderator and neutron economy properties, although their heat transfer characteristics are less favorable than water. Fuel in present OMR designs is composed of uranium alloyed with molybdenum and is in plate form.

The advantages of the OMR concept include the possibility of superheated steam production, low capital cost, negligible corrosiveness, and excellent safety characteristics under proper design conditions. Disadvantages include high fuel fabrication cost, possible decomposition of organic moderator, and less efficient heat transfer.

Sodium Graphite Reactor

Other concepts which have evolved to avoid the high pressure requirements, yet produce superheated steam, include the liquid metal reactors. These reactors are best exemplified by the sodium graphite reactor (SGR). This reactor is based upon the use of liquid sodium metal as a coolant and graphite rods as moderator. Fuel elements are composed of slightly enriched uranium and are arranged in lattices.

The advantages of the SGR include the following: high temperatures are achievable without pressurization; corrosion problems are minimized; heat removal characteristics are excellent, and with proper design a good conversion ratio of U-238 or thorium is possible. Disadvantages include the chemical reactivity of sodium with air or water, intermediate heat exchange equipment requirements, special core structural problems, and the need for special equipment to handle liquid sodium and prevent solidification during shutdowns.

Gas Cooled Reactor

Still another concept which has the special advantage of permitting high temperatures is the gas cooled reactor (GCR). The GCR, as its name indicates, uses gas such as helium, nitrogen, or carbon dioxide as a coolant and is moderated by either graphite or water. Because of the excellent nuclear properties of either helium or carbon dioxide, the GCR is able to operate on a natural uranium fuel cycle, hence, certain fuel economies are obtainable. The main disadvantages of the GCR are poor heat transfer efficiency, low power density, and high capital cost.

Homogeneous Reactor

All the reactor concepts previously described are of heterogeneous type, that is, the fuel and coolant are separate. It is reasonable to suppose that certain economies may be gained by combining fuel, coolant, and moderator into one medium. This system has evolved into the homogeneous reactor.

The advantages of this concept are many, of which the elimination of fuel fabrication costs, continuous fuel processing, good overall heat transfer characteristics, and possibilities of self-control are the most important. But with today's technology, the problems yet to be resolved in the homogeneous reactor are considerable. Such considerations as corrosion, containment of radioactivity, equipment for coupling nuclear, hydrodynamic, and mechanical systems, and maintenance are still in the research stage. Until these problems are resolved, a full evaluation of the homogeneous reactor cannot be made.

Fast Breeder Reactor

An advanced concept is embodied in the fast breeder reactor. This reactor has a double purpose--to produce power and to breed fuel.

In fast breeder reactors, no moderator is required since the reactor utilizes fast neutrons. This results in an advantage in the conversion of the fertile material since higher neutron economies prevail in the fast neutron range. In experiments with fast breeder reactors, liquid sodium has been used as a coolant.

The advantages of the sodium cooled fast reactor are the possibility of producing more fuel than is consumed, small reactor core size, and good heat removal characteristics. Disadvantages include the difficulties in handling liquid sodium, fast-acting control system requirement, and fuel handling problems.

Other Types of Reactors

There are other types of reactors which offer even more novel approaches than the fast breeder reactor to the problem of converting nuclear energy to usable energy. Such concepts include the molten salt, pebble bed, boiling sulphur, fluidized fuel, thermal breeder, and dust fueled reactors. The potential of these concepts is unknown, but with future development the economic and technical promise of any of these types may completely outmode the better known concepts of today.

Nuclear Power Costs

The economics of nuclear power are presently subject to much conjecture and supported with very little experience in operating plants since those reactors now under construction or in actual operation are products of the first generation of nuclear power. Since first generation products of any technical innovation include large research and development costs, it is obvious that these reactors present an inadequate measure of the present and future economic potential of nuclear power. Present cost estimates of nuclear power must perforce be largely derived from design studies, experimentation, and assumptions.

Present Costs

Costs of the first full-scale civilian power reactor built in the United States (at Shippingport, Pennsylvania) are an excellent example of the operation of this principle. When research and development costs are added to those of design and construction of the Shippingport reactor, power costs exceed five cents per kilowatt-hour, a cost several times of conventional thermal power plants and as much as 10 times the predicted ultimate costs of nuclear power.

Accurate cost estimating is further handicapped by the fact that the Shippingport reactor is the only reactor in the United States from which a fair amount of operating experience useful for economic analysis has been gained. This situation will gradually be clarified, however, with the start-up

and operation of several power reactors presently under construction or recently placed in operation.

Because there are few full-scale nuclear power plants with substantial operating experience, the economics of nuclear power must be derived from a wide variety of studies, pilot plant experience, and preliminary designs. Many of these paper studies may be fairly accurate, but several years of operating experience must be accumulated before a reliable base will be established for cost estimating purposes.

The most useful source of economic information on nuclear power costs is the Atomic Energy Commission. The Commission, through its responsibility for sponsoring research and development of specific reactor types, must have accurate appraisals of the economic potential of each reactor. Therefore, reliable predictions of power costs from specific reactor types are a necessity.

Prior to discussing the recent cost data of specific reactors published by the Atomic Energy Commission, it is useful to point out the important categories involved in nuclear power costs. These categories include fixed charges, fuel cycle costs, inventory charges, and operation and maintenance.

Fixed charges are common to all engineering projects and include the cost of money, depreciation, and interim replacement of equipment. Factors which determine these fixed charges in a nuclear power plant include the capital cost of the plant,

interest rates, taxes, insurance, the power output of the plant, plant factor, and the expected lifetime of the equipment and structural components of the plant.

Fuel cycle costs are simply the cost of fuel for the plant. They are analogous to the cost of gas or oil for the conventional power plant.

Inventory charges are the carrying charges applied to fuel kept on hand for reactor refueling or in the stage of reprocessing. Because of the heavy investment in this fuel, carrying charges must be applied. In heavy water reactors, an additional inventory charge is applied to the heavy water itself in view of its large cost.

Operation and maintenance costs, as the names imply, include supervision and administration, operation and maintenance labor, and materials and supplies.

Because capital costs are the most important factors in the fixed charge category, it is useful to illustrate the capital costs of nuclear power plants presently operable, being constructed, and planned. Table 15 lists capital costs of a number of representative plants, of which all are advance estimates except for Shippingport and Dresden.

Certain trends are noticeable from this table. Among these is the general rule that the larger the reactor, the smaller the unit capital cost per kilowatt. This characteristic is true in conventional power plants, but is even more

TABLE 15

GENERAL DATA ON NUCLEAR POWER REACTORS
IN THE UNITED STATES AND THE BRITISH COMMONWEALTH^{1/}

Name of reactor	Location	Reactor	Status	Net : capacity, in: : megawatts	Unit cost, in dollars per net kilowatt
Shippingport	Pennsylvania	Pressurized water	Operable	60	1,220
Yankee	New York	Pressurized water	Under test	110	470
Indian Point	New York	Pressurized water	Being built	255	390
Elk River	Wisconsin	Boiling water	Being built	22	540
Humboldt Bay	California	Boiling water	Planned	46.5	420
Northern States	South Dakota	Boiling water	Being built	62	320
Dresden	Illinois	Boiling	Operable	180	280
Florida West Coast	Florida	Gas cooled	Planned	50	570
Piqua	Ohio	Organic	Being built	11.4	790
Enrico Fermi	Michigan	Fast breeder	Being built	94	570
Carolinas Virginia	South Carolina	Heavy water	Being built	17	1,350
Candu	Canada	Heavy water	Being built	200	320
Hinkley Point	England	Gas cooled	Being built	500	340

^{1/} Costs of Nuclear Power, TID-8506, Office of Technical Services,
July 1959.

pronounced in nuclear power plants. For this reason, we may anticipate that nuclear power plants of the future will be fairly large in capacity.

A second trend in the capital cost of nuclear power plants, though not readily apparent from the table, is the downward unit capital cost with each new proposal. The first nuclear power plants required the development of new materials and equipment, fabrication and assembly to rigid specifications, elaborate instrumentation, and extreme provisions for safety. With industry now having gained experience with new materials and techniques, costs dependent upon these factors are decreasing. In addition, nuclear power is becoming an industry-supported product, and the spirit of American enterprise has created competition among the industries producing different reactor types, inevitably leading to lower costs.

Future Costs

There seems to be general agreement among workers in the field of atomic energy that atomic power in the United States will become competitive with conventional power, at least in high-cost energy areas, by about 1970. To make this possible, strong efforts must be made to simplify design, to increase thermal efficiencies, to decrease construction costs, to get maximum energy out of the fuel, and to minimize operation and maintenance costs. The goal of competitive atomic power cannot be reached with the construction of a few experimental and

prototype plants, but progress toward this goal can confidently be expected as large-scale plants, some of which are under construction now, are brought into production.

A 10-year program, designed to make nuclear energy from large power plants economically competitive with conventional plants in high-power cost regions of the United States, has been charted by the Atomic Energy Commission. This program is the result of an intensive study by the Reactor Development Division of the Commission, undertaken in June 1959, and presented to Congress at the "state-of-the-industry" hearings held by the Joint Committee on Atomic Energy in the spring of 1960. The two fundamental objectives of this civilian atomic power program are:

1. Reduce the cost of nuclear power to levels competitive with power from fossil fuels in high-energy cost areas in the United States within 10 years (reckoned from 1958, when the commission's objective was first stated).
2. Support a continuing long-range program to further reduce the cost of nuclear power in order to increase the economic benefits and extend the benefits to wider areas.

High-cost energy areas are defined as areas where fossil fuels cost \$0.35 per million Btu or higher. (For comparison, oil and gas prices in the major power generating regions in California range from \$0.30 to \$0.35 per million Btu.) Representative conventional power costs in the high-cost energy areas are estimated

to be about seven mills per kilowatt-hour for a 300 megawatt single-unit station, operating at an 80 percent load factor, with 14 percent fixed charge rate on an estimated capital cost of \$166 per kilowatt. Competitive nuclear power is considered to be achieved when utilities are able to build and operate nuclear power plants on the basis of their economic advantage. Primary emphasis in the program was placed on large power reactors of 300 megawatt capacity, since it is in the larger sizes that the nuclear plant will most quickly prove economic.

Capital Costs

As the basis of its 10-year program, the Atomic Energy Commission evaluated eight major reactor concepts currently under development in the civilian reactor development program, established the present economic and technological status of each concept, delineated the specific technical improvements that could be foreseen for each, and made estimates of the impact these improvements would have on the cost of nuclear power. The commission also outlined the development program, including cost estimates, that would be needed to realize the improvements. The cost data developed during this study are tabulated in Table 16. It will be noted that, in a number of cases, the capital costs of future plants are only slightly above \$200 per kilowatt, and the resulting power costs are between seven and eight mills per kilowatt-hour. Also, in one case (organic), the capital and power costs are well below \$200 per kilowatt and seven mills per kilowatt-hour, respectively.

ESTIMATED NUCLEAR POWER COSTS IN
ATOMIC ENERGY COMMISSION'S 10-YEAR PROGRAM^{1/}

Reactor type	Energy costs with 14 percent annual :cost, in: fixed charges, and 80 percent capacity factor						
	:dollars :Capital cost,:		Fuel cost, :		Operation and main- :		Total cost,
	: per :in mills per :in mills per :		tenance insurance, in :		: in mills per		
	:kilowatt:kilowatt-hour:kilowatt-hour:		mills per kilowatt-hour:kilowatt-hour:		kilowatt-hour:		
Pressurized water							
Present	244	5.05	3.38	0.85	9.28		
Future - 1966	213	4.40	2.56	0.84	7.80		
Boiling water							
Present	263	5.26	3.47	0.88	9.61		
Future - 1967	215	4.31	2.29	0.85	7.45		
Organic							
Present	220	4.39	5.72	1.34	11.45		
Future - 1967	177	3.53	1.83	1.31	6.67		
Sodium Graphite							
Present	303	6.05	7.68	0.99	14.72		
Future - 1968	224	4.47	2.00	0.95	7.42		
Gas cooled-enriched							
Present	380	7.60	3.35	.94	11.89		
Future - 1968	232	4.63	2.62	.73	7.98		
Heavy water							
Present	360	.708	4.22	1.23	12.50		
Future - 1969	296	5.80	1.21	1.19	8.20		
Fast breeder							
Present	255	5.10	7.10	1.05	13.25		
Future - 1969	217	4.43	1.99	1.04	7.46		

^{1/} Nucleonics, "AEC Puts Together a Long Range Power Reactor Program", April 1960, page 73.

Note: 1. Data are based upon 300 megawatt power plant.

2. Future costs are predicated upon extensive research and development, plus construction of prototype reactor plants during 1961-69 period.

An encouraging development, tending to support the Atomic Energy Commission forecasts, is the serious consideration being given by two leading utilities in California--the Pacific Gas and Electric Company and the Southern California Edison Company--to the construction of a large nuclear power plant in each of their respective systems. Southern California Edison Company has recently concluded negotiations with Westinghouse and Bechtel Corporation for the design and construction of a 375 megawatt pressurized water reactor power plant to be located in the Southern California area. Studies made by the company have indicated that such a plant would be economically competitive with conventional fuel plants, when considered for the duration of the plant's operating life. The estimated capital cost approaches 78 million dollars, about \$208 per kilowatt, and thus is somewhat lower than the future predicted cost of a large pressurized water plant in the Atomic Energy Commission program, as listed in Table 16.

Another recent California development is the acceptance by the Atomic Energy Commission of a joint proposal from the Cities of Los Angeles and Pasadena, to build a 50,000 kilowatt boiling water reactor power plant. The cities will provide the site and the turbogenerating equipment, while the Atomic Energy Commission will procure and own the reactor portion. The selected site is near the town of Saugus about 25 miles northwest of Los Angeles.

Of further interest in the field of economics of nuclear power is a study^{1/} recently made for the Department of Water Resources by Stanford Research Institute on the impact of nuclear energy on the State Water Facilities, specifically the conveyance of water from the Delta to Southern California. The State Water Facilities consist of dams, reservoirs, aqueducts, pumping plants, and hydroelectric generating plants, designed to serve various areas of the State with water for municipal, industrial, and agricultural use. The means of financing this program were provided by the passage of legislation (Burns-Porter Act) in November 1960, which authorized the issuance and sale of bonds in the amount of \$1,750,000,000. A key feature of the State Water Facilities is the California Aqueduct which transports water from the Delta (near the San Francisco Bay area) to Southern California.

In its study, Stanford Research Institute considered the power demands of a certain group of pumping plants and predicted that the costs of nuclear energy applications to supply these pumps under the conditions of the State Water Facilities plan will become competitive with conventional energy applications between 1977 and 1984, depending upon plant size, financing methods, and other variable factors. Assuming a 25-year life for a nuclear power plant, nuclear energy will become competitive with the first power plant to be built in the system, and will

^{1/} "The Impact of Nuclear Energy on the State Water Facilities of California", by Stanford Research Institute.

become increasingly favorable as new units are added to match the water demand buildup through the years. Stanford Research Institute predicted that capital costs of large nuclear power plants will decline to a level of about 20 percent above that of conventional power plants by 1970, and will reach equality with conventional plants by 2020.

The Atomic Energy Commission predictions of capital cost trends, as shown in Table 16, are more conservative, at least for the latter part of this decade, than those of the Stanford Research Institute. Capital costs will be reduced as more experience is gained in manufacturing the many items of special equipment required for a nuclear power plant. Also, experience with operating plants may reveal that cheaper materials, less rigid fabrication techniques, fewer special components, less elaborate instrumentation, simpler refueling equipment, and less extensive provisions for safety will be acceptable. These factors should tend to materially reduce capital costs in future plants.

Fuel Costs

Since capital costs will remain high for the foreseeable future, costs of nuclear fuel must be proportionately lower than that for fossil fuels in order for nuclear power to be competitive with conventional power.

The Stanford Research Institute feels that nuclear fuel costs will decline to about four mills per kilowatt-hour in 1970, to two mills by 1995, and to 0.5 mill by 2020.

Some of the means by which reductions in fuel costs will be gained are as follows:

1. Increase in the amount of heat energy extracted from a unit weight of fuel, through longer exposure in the core and better heat transfer.
2. Increase in demand for fuel elements, leading to economies in fabrication and processing techniques.
3. Reductions in storage and chemical reprocessing charges.

No technical breakthroughs leading to dramatic rates of improvement in these aspects are expected to occur; rather, it is likely that small gains in each will be effected from year to year, producing a gradual downward cost trend.

Because of the comparatively high capital costs of nuclear power plants, and the potentially low fuel costs, it is safe to assume that nuclear plants will usually form the base load of any power system. This characteristic has unusual significance when applied to the pumping requirements of the State Water Facilities. In the event that pumping energy requirements were maintained at a constant rate, a nuclear power plant within the system could be operated at a high capacity factor, a definite economic advantage.

Nuclear Energy for Saline Water Conversion

In addition to application of nuclear energy to the generation of electrical power, it may also be used in the form of heat for application to the conversion of salt water

to fresh. All large capacity sea water conversion plants in use today are of the distillation type and thus use heat, usually in the form of low-pressure steam, as an energy source. Certain economies, such as in fuel fabrication, can be realized in reactors that produce low temperature steam. Nuclear energy, therefore, has encouraging potential advantage when used in distillation processes. Studies have shown that heat from large size reactors in the future may be cheaper than that from fossil fuels, but even when combined with the most efficient distillation plant now available, the cost of the product water is not competitive with normal natural fresh water sources.

Isotope Applications

In addition to nuclear power, the Department of Water Resources has a direct interest in utilization of several other aspects of nuclear phenomena. These may have an immediate or potential application to water development problems. Radioisotopes, for instance, are being used in a number of ways. Recent developments in the quantitative determination of certain stable isotopes may have great potential benefit in hydrology. The use of nuclear explosives for improvement of ground water resources also has been studied, but direct benefit from this activity seems quite remote at the present time. Studies by the department connected with these processes are described below.

Utilization of Radioactive Isotopes

The Department of Water Resources has been licensed by the Atomic Energy Commission to possess certain quantities of radioactive materials for use in its program. By-product material licenses have been issued and purchases made of cesium-137 and of actinium-227 as sealed sources. A special nuclear material license has been granted to the department for possession of up to 10 grams of plutonium-239, as sealed plutonium-beryllium neutron sources. Two of these sources are currently in use. In addition the department has purchased six neutron sources, containing a total of about 30 milligrams of radium-226. This element is not under licensing control by the Atomic Energy Commission.

Various units of the department have been actively engaged either directly or in cooperation with other agencies in activities involving radioactive isotopes. These activities are described in this section.

Principles of Soil Moisture and Density Measuring Devices. Certain radiation phenomena lend themselves admirably to the rapid, non-destructive measurement of the moisture content and the density of granular materials, such as soils. When a source emitting high energy or "fast" neutrons is placed in the vicinity of a hydrogenous medium, the neutrons are moderated, or "slowed", almost exclusively by collisions with nearby hydrogen atoms. Consequently, the number of slow neutrons produced is proportional to the density of hydrogen atoms in the surrounding medium and is essentially independent

of its other chemical or physical properties. In soils water is the principal contributor of hydrogen atoms.

A detector which is sensitive only to slow neutrons is placed close to the fast neutron source, and enclosed in a device called a neutron probe. When this probe is placed in the soil, pulses due to slow neutrons will register on suitable counting equipment. The count rate may then be related to the soil moisture in the vicinity of the apparatus by means of a prior calibration of the instrument.

By application of somewhat similar principles through the use of a source of gamma radiation and a gamma detector in a density probe, the electron density of the atoms composing the surrounding soil may be determined. Count rates resulting from this measurement may then be related to the bulk density of the medium in which the device is placed.

The Department of Water Resources is now using portable instruments which contain radioactive sources to secure field data and to provide valuable information for use in water resource development activities.

Vegetative Water Use Studies. A thorough knowledge of the consumptive use of water is essential in water development planning. One of the methods whereby water use by vegetation (evapotranspiration) may be evaluated is by accurate field measurement of the depletion of moisture from the soil.

In determining water use by a selected crop, a neutron probe is lowered into the soil through a cased bore

hole in the field in which the crop is being raised to depths up to 25 feet. Moisture readings are made at selected depths in the soil, normally at 1-foot intervals. These measurements are made periodically during the growing season. By this procedure, it is possible to determine water content changes in the root zone of the soil, and with knowledge of the quantity of water applied, water depletion for the crop is determined. These measurements are being made at several key stations throughout the State. Areas in which neutron probes are being used by the department for evapotranspiration studies include Kern County near Bakersfield, Western San Luis Obispo, and Santa Barbara Counties, the Sacramento-San Joaquin Delta area, the foothill areas of Placer and Nevada Counties, and Shasta County. Figure 18 depicts the equipment in operation at one of these field sites.

Land Subsidence. Soil moisture and soil density probes are being used at test sites located in subsidence areas on the west side of the San Joaquin Valley. The interest of the Department of Water Resources in these areas arises from the fact that the proposed route of the California Aqueduct traverses the areas. Data obtained from this investigation yield the rate and amount of penetration of water through the soil from the surface to a depth of 200 feet. By this method, valuable information on subsurface conditions, which should materially assist in the design and construction of the aqueduct is being collected.

Ground Water Recharge. The Department of Water Resources is currently cooperating with the United States Department of Agriculture, Agricultural Research Service, in studies of the movement of ground water. For this purpose, neutron probes are being utilized for soil moisture measurements. Field studies are being conducted in the San Joaquin Valley, in connection with a program to investigate ground water recharge.

Compaction Control. Rapid, nondestructive soil testing methods, which are provided by the use of devices containing radioactive sources, are particularly useful in many areas of earthwork construction. Instruments have been developed which are designed to operate on the soil surface, and to indicate its moisture and density to a depth of about 1 foot. The Department of Water Resources has made evaluation studies with these devices on several embankment projects in connection with its construction activities. Close liaison is being maintained with the State Division of Highways, which has several of these instruments in use.

Snow Measurements. Rapid and accurate determination of the water content and density of snowpacks is important in prediction of total water in storage in watershed areas. Studies of the possible application of radioactive probes to this purpose are being made by the United States Forest Service, in cooperation with the Department of Water Resources. This work is being conducted at the Central Sierra Snow Laboratory, near Soda Springs.



Photograph by DWR

Figure 18

Soil moisture probe in operation on an alfalfa field in Shasta County. This is one of the department's vegetative water use plots.

Isotopes as Tracers

There is a real need in hydrologic studies for tracers which will permit the identification of flow paths and calculations of flow velocities in various types of water bodies. Radioactive tracers, which may be detected accurately and precisely even in very low concentrations appear to fill this need ideally.

At present the Department of Water Resources is participating in such studies to the extent of maintaining close liaison with members of other agencies, who are conducting a few studies of this nature, as described below.

Seepage Studies. The radionuclide tritium has been used in a project to determine the magnitude and extent of seepage of water from canals. Personnel of the United States Bureau of Reclamation and the University of California, Department of Engineering, have conducted seepage studies on a test section of the Madera Canal.

Flow Studies. Stream flow and silt transfer studies utilizing radioactive tracers are being conducted by the University of California, Department of Engineering. This work promises to provide information which should find many direct applications in departmental hydrologic activities.

Possible Use of Stable Isotopes

Recent studies have indicated that considerable information regarding the source and history of surface and ground waters may be obtained by analyses for the stable

isotopes of hydrogen and oxygen normally present in such waters. These isotopes include hydrogen-1 and hydrogen-2 (deuterium), and oxygen-16, oxygen-17, and oxygen-18. Because of differences in volatility caused by the normal distribution of these isotopes in water, there is a tendency to enrich waters which are subject to free evaporation, in the heavier of these isotopic species. Similar phenomena govern the condensation of water vapor which falls as precipitation. Thus, by a careful study of isotopic ratios in waters, much information of considerable importance to hydrology may be obtained. The department is actively pursuing an investigation to determine the feasibility of further studies in this area toward the solution of some major hydrologic problems.

Possible Uses of Underground Nuclear Explosions

Another application of nuclear energy having potential value to the State of California is the possible beneficial results, from a water supply standpoint, to be achieved from an underground nuclear explosion. Such an explosion might conceivably affect a ground water aquifer so as to facilitate recharge, increase storage capacity, increase rock permeability, or break through a barrier in order to interconnect adjacent aquifers. An underground explosion might also produce a great amount of recoverable heat at moderate cost. The heat could possibly be released at a controlled rate by use of a transfer agent, such as water or gas, and used for the production of power or in the form of heat for the conversion of salt water to fresh.

Study and experimentation in the peaceful uses of nuclear explosive devices were initiated at the University of California Lawrence Radiation Laboratory at Livermore in 1957, in connection with the AEC Project Plowshare Program. In addition to the possible applications relating to ground water, other uses being investigated include excavation, isotope production, recovery of oil from shales and tar sands, mining, and applications to scientific studies in seismology, geology, and special chemical reactions.

The department has participated in discussions with members of the laboratory staff concerned in Project Plowshare studies in an attempt to evaluate effects and possible benefits of an underground nuclear explosion in an aquifer. Insufficient information is available, however, to assess the effects of such an explosion on the geological formations in which ground water occurs and on the water itself, and further investigative work is not planned at this time.

The possibility of producing controlled power or heat from an underground explosion appears quite remote. Some preliminary studies of the technical feasibility and economics of a process for transfer of residual heat from an underground explosion to water have been made by Professor I. Fatt of the University of California^{1/}, showing the probable costs to be quite high. Not only are formidable engineering problems

^{1/} I. Fatt, "A Study of the Feasibility of Using an Underground Nuclear Explosion as a Source of Heat Energy for the Distillation of Sea Water", University of California, Berkeley, California, Series No. 75, Issue No. 17, September 24, 1959.

involved in a project of this nature, but the further unfavorable fact exists that a period of many years must elapse after the firing before the rock cools to a point where the heat can be extracted.

The practicability of underground nuclear explosions to alter ground water conditions, or to furnish heat for salt water conversion or power, appears quite remote at the present time and should only be considered to be a theoretical possibility until extensive further experimentation has been performed.

Summary

The utilization of nuclear energy in development of California's water resources may take two forms--as low temperature steam for a saline water conversion process, and as a steam producer for power generation. While present costs of nuclear energy are high there is growing assurance that this energy source (converted to either heat or electricity) will ultimately cost less than energy from conventional sources. This means an increasing share of future power demands will be shifted to atomic plants, a trend fostered also by dwindling fossil fuel reserves. It is not likely that a nuclear-powered conversion plant will be built in the State for many years. However, studies have shown that nuclear energy will be economically preferable and conventional in supplying the major pumping power requirements for the State Water Facilities if the power generating plants are built by the State. Studies of alternative power sources are being

made, however, and a decision as to the source of power has not been made at this time.

With respect to radioisotopes, tangible benefits have accrued from their use as a tool in facilitating the measurement of land and water use efficiencies. It is anticipated that further uses will be devised as experimentation is continued and techniques improved.

CHAPTER IV. NONCONVENTIONAL ENERGY SOURCES

Introduction

Man's need for sources of energy to activate his machines and devices has paralleled human progress and civilization. At the present time, the major sources of energy are fossil fuels and power derived from falling water. Within the next one or two decades nuclear energy will probably assume a substantial role in meeting power demands in California. Nevertheless, a survey of less conventional energy sources for possible use in water demineralization and to augment or supplement basic power sources is of interest. Most so-called nonconventional sources considered in this chapter have already had a long history of rather limited exploitation in the United States, as well as in other parts of the world.

Within the recent past, various individuals and groups have developed suggestions and proposals for the use of a wide variety of sources of power. Energy beneficial to mankind lurks in seemingly strange places or in unexpected forms. The purpose of this chapter is to discuss and to appraise the present and probable future of some of these forms of energy, with primary regard to their possible use as sources of energy for water demineralization, and secondarily for power, especially for isolated locations.

The United Nations Educational Scientific and Cultural Organization (UNESCO) has, in recent years, given special attention to the possibilities of employing

unconventional energy sources, especially in the arid and semi-arid regions of the world. As a part of its regular scientific activities it has undertaken a broad review of current research in various countries. In 1954, UNESCO organized an international symposium^{1/} held in India, on wind and solar energy. In 1955, UNESCO gave financial support to a World Symposium on Applied Solar Energy^{2/}, held at Phoenix, Arizona. More recently, UNESCO assisted the Department of Economic and Social Affairs of the United Nations in a comprehensive study^{3/} of many types of nonconventional energy sources.

At the present time, UNESCO and the World Meteorological Organization are undertaking the first worldwide survey of solar radiation distribution, mapping the daily and annual variations, dependence on altitude, and related factors. The study is being conducted in cooperation with a specialized solar observatory and makes use of observed data gathered during the recent International Geophysical Year. At the present time there exists no simple and inexpensive instrument for measuring solar radiation, useful in the determination of sites most suitable for solar energy development. UNESCO is providing financial assistance to developing such an instrument as well as for testing other solar energy apparatus.

^{1/} UNESCO, "Wind and Solar Energy; Proceedings of the New Delhi Symposium", Paris, 1956.

^{2/} Stanford Research Institute, "Proceedings of the World Symposium on Applied Solar Energy, Phoenix, Arizona, November 1-5, 1955", Menlo Park, California, 1956.

^{3/} United Nations, "New Sources of Energy and Economic Development", E/2997 Department of Economic and Social Affairs, New York, 1957.

A comprehensive symposium^{1/} on all phases of the utilization of solar energy was held at Madison, Wisconsin, in 1953. It was sponsored by the United States National Science Foundation and the University of California. The purpose of the meeting was to discuss the possibilities of solar energy utilization and to determine the areas where research should be encouraged.

In 1958, the French National Center of Scientific Research conducted, at Montlouis, a symposium on the applications of solar energy in the modern world. Subjects discussed ranged from small cooking devices, water and house heaters, to solar power devices in space vehicles.

Solar Energy

Solar radiation has long been used to increase the rate of plant growth, to lengthen the growing season by the use of greenhouses, and to evaporate saline water in the salt industry. Modern solar energy applications are still largely in the research stage, varying from observations of solar radiation to advanced experimentation on a worldwide basis in such countries as Algeria, Australia, the Congo, Burma, Egypt, France, French West Africa, India, Israel, Italy, Japan, the Union of South Africa, Russia, the United Kingdom, and the United States.

^{1/} Daniels, F., and Duffie, J. A., "Solar Energy Research", The University of Wisconsin Press, Madison, 1955.

The quantity of energy radiating from the sun is very nearly constant. Outside the atmosphere of the earth, and on a surface perpendicular to the rays of the sun, this radiant energy is about 7.4 Btu per square foot per minute. Due to losses sustained in passing through the upper atmosphere, and through clouds in the lower atmosphere, radiant energy of the sun is greatly depleted and extremely variable in intensity when it reaches the earth's surface. At Fresno, California, for example, the maximum radiation rate occurs in July, at a little past mid-day, and equals about 5 Btu per square foot per minute. The minimum radiation occurs in December and for a comparable time of day equals about 2 Btu per square foot per minute. Cloudiness would, of course, reduce the energy received to a lesser value.

The average daily energy on a horizontal surface in a sunny climate, such as the southwestern United States, is from 1800 to 2000 Btu per square foot per day. Typical observations in areas where solar intensity is relatively high are given in Table 17.

Basic techniques utilized to convert the radiation of the sun into usable energy are classified into two groups.

1. Processes utilizing solar heat.
2. Processes utilizing light from the sun.

In addition, there are being developed means for the direct conversion of heat into electricity, whether the heat be derived from the sun or from other thermal sources. These processes will be described later in this chapter. The so-called solar battery is also briefly discussed in this section.

TABLE 17

AVERAGE SOLAR RADIATION ON A HORIZONTAL SURFACE

(Btu per square foot per day)

Location	:Minimum monthly:	Maximum monthly:	Yearly
	:Average, in Btu:	Average, in Btu:	Average, in Btu
	: per square : per square : per square	: per square : per square : per square	: per square
	: foot per day	: foot per day	: foot per day
Honolulu, Hawaii	1,395	2,380	1,930
El Paso, Texas	1,200	2,730	2,030
Fresno, California	610	2,620	1,660
Riverside, California	782	2,207	1,558
Santa Maria, California	867	2,399	1,817
Albuquerque, New Mexico	1,085	2,749	1,892
Las Vegas, Nevada	845	2,771	1,822
Salt Lake City, Utah	443	2,192	1,442
Phoenix, Arizona	1,061	2,710	1,925

Techniques for Solar Heat Utilization

The range of temperatures attained in solar devices depends largely on the degree of concentration of solar rays and is accomplished by the use of mirrors or collectors. Low temperatures (below 212° F) are relatively easy to achieve. For this purpose, flat plate collectors are frequently used. Black radiation-absorbing metals are placed in a transparent enclosure and are employed to heat water, or other liquid, and are utilized for the transfer of usable heat. Low temperature processes have many applications, as for example, for space and water heating and for the distillation of water (as was described in Chapter II).

Lenses or reflecting mirrors are needed to create temperatures higher than a few hundred degrees. As these lenses or mirrors capture only the direct rays of the sun, they must be continually rotated so as to keep the sun's rays in focus. The heat captured and the temperature created are dependent on the quality of the mirror surface and the accurate shaping of the parabolic collectors. As a consequence, differentiation is frequently made between medium temperature devices and high temperature furnaces. The heat in the former, below about 1,800° F., may be used directly in low-temperature furnaces and in solar cookers, or may be transferred through liquid or gaseous media to operate engines of various types. High-temperature furnaces (1,800 to 6,300° F.) are chiefly used in industrial and research applications to treat refractory and metallic materials, to induce chemical reactions, and to create steam of high temperature and pressure.

For certain remote areas of California, the use of solar energy for direct distillation of saline water or for production of power for pumping and domestic electrical use may prove feasible. For such regions, Dr. Vannevar Bush has recently proposed the use of slow-moving solar heat engines employing air heated by the sun in flat plate collectors as an energy source.

Historically, California has been the locale for several solar steam engines built and operated early in the present century. One was built in 1901 in Pasadena, and during the same year another, developing 11 horsepower, was

constructed and operated at the Ostrich Farm in South Pasadena. In 1905 and 1908, two solar-mechanical devices (15 and 20 horsepower, respectively) were constructed and operated at Needles, California.

Techniques for Solar Light Utilization

Solar radiation in the form of light may be converted to useful forms of energy by employing various photochemical and photoelectric processes.

The basic concept in photochemical processes is that a number of chemical reactions may be activated by sunlight in which the reactants themselves, or a photocatalyst mixed with the photochemical, absorb solar energy. Of the several photochemical processes, photosynthesis is the most useful. Research work on this process is concerned not so much with the efficiency of chemical conversion as it is with obtaining means of utilizing and storing the greatest possible quantity of solar energy by means of plant life. This involves the proper selection of plants and the creation of optimum conditions for their growth. Interest is especially being centered on single-celled algae that can grow and multiply in water.

Photoelectric conversions are of much interest in direct utilization of solar energy. One device is the photovoltaic cell utilized in photographic exposure meters. An electric current is produced when solar rays strike a light sensitive material, such as selenium. Modern cells, developed as a result of research in semi-conductors, employ silicon and are called solar batteries. Minute amounts of arsenic,

melted with silicon of high purity, produce negative-type silicon. The material is produced in the form of thin wafers which are subsequently covered with boron to produce a thin top layer of positive-type silicon. As a result of the juxtaposition of negative-type and positive-type silicon, an electric voltage is generated when light strikes the junction of the layers. At the present time, the efficiency of the solar battery is low. It is anticipated, however, that continuing research will eventually produce a device of relatively high efficiency for the direct conversion of solar rays into electricity.

Geothermal Energy

Probably prehistoric man knew and used hot water and steam produced in the interior of the earth. However, the actual production of mechanical and electrical power from steam or hot water originating in subterranean sources of heat dates back only to 1904, although investigations of such sources of energy cover a period of almost a century.

Regions of the earth where readily observable sources of geothermal energy are available are extremely limited. Principal sources are located in Italy, Iceland, New Zealand, Alaska, and in the Western United States. In California, such sources are located in Sonoma County, Lassen National Park, and in the Imperial Valley.

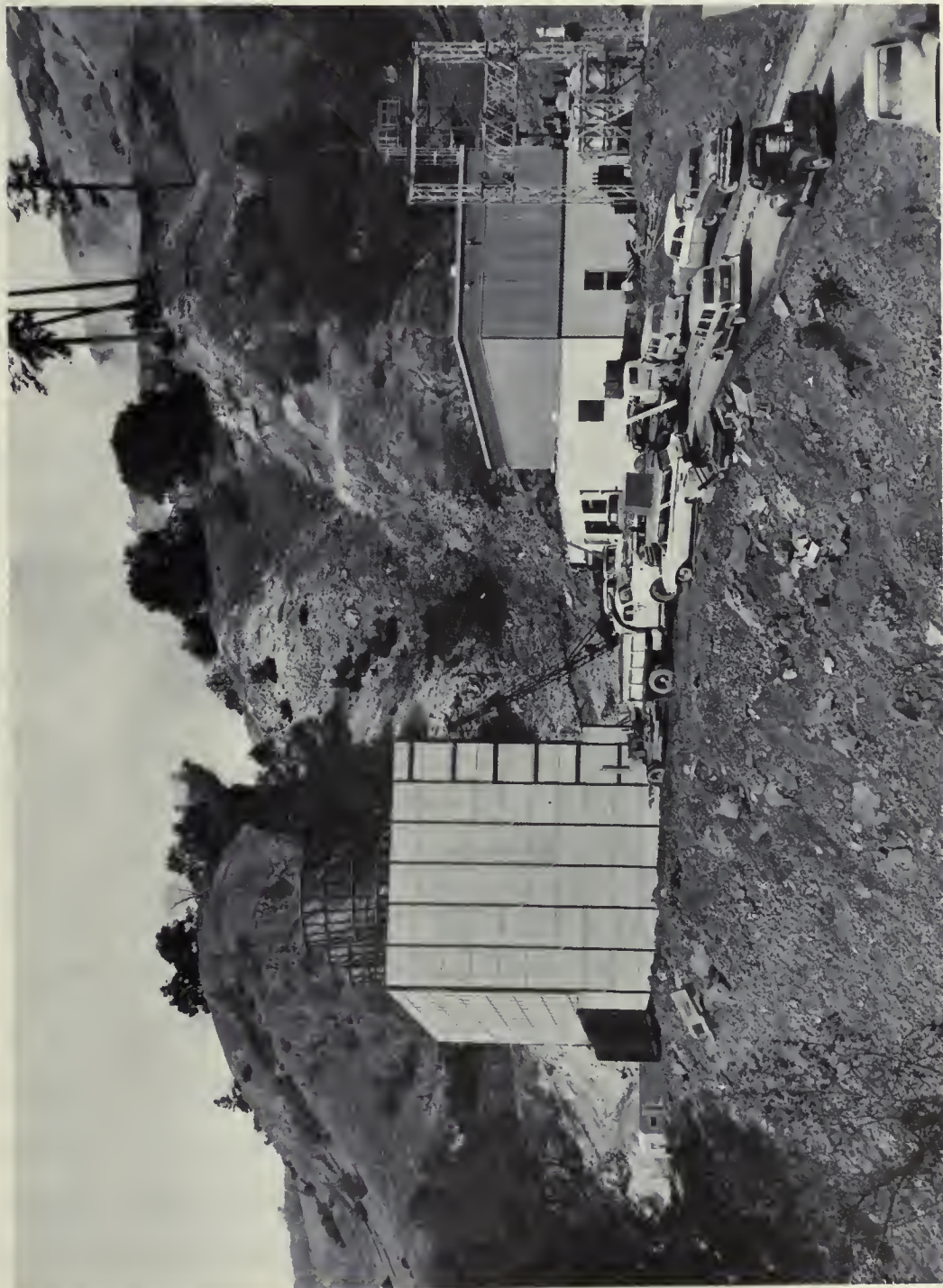
Practical utilization of geothermal energy for the generation of electricity is well established in Italy, where power facilities had attained a total capacity of 274,000

kilowatts by the end of 1954, with an output of nearly 2,000 million kilowatt-hours annually. In Japan, investigation and research in this field includes a 30-kilowatt pilot plant tested in 1951, numerous test borings, and plans for a 3,000-kilowatt installation. In New Zealand, a 37,500-kilowatt geothermal steam plant is under construction. Other examples of the applications of geothermal energy include a 275-kilowatt plant in the Katanga mining area in the Congo; two experimental units aggregating 25,000 kilowatts capacity authorized for construction in Mexico, State of Hidalgo; and plans for facilities in Chile with an initial capacity of 2,000 kilowatts, and an ultimate generating capacity of about 60,000 kilowatts, employing heat from the Tatio geysers near Antofagasta. The Pacific Gas and Electric Company has recently (July 1960) placed in operation a 12,500-kilowatt electric plant using geothermal steam found at the Geysers, Sonoma County, California. It is the first commercial geothermal power plant in the United States and the world's first privately financed geothermal electric power plant. Figure 19 shows the plant during the final phase of construction.

Large-scale use has been made of geothermal energy in Iceland for heating the City of Reykjavik and it is estimated that the steam field near the city may yield a total power capability of approximately 300,000 kilowatts. The feasibility of heating by geothermal energy is being investigated in other areas of the world, including the Western United States, regions of the Soviet Union, and the Far East.

Theoretically, geothermal energy is of almost unlimited extent originating in the heat of the interior of the earth itself. Over most of the earth's crust, the observed increase of temperature with depth is remarkably uniform, averaging about 1° F. with every 60 feet of depth (increase of temperature with depth is called temperature gradient). Visible manifestations of internal heat occur as volcanic action at high temperatures and as springs of hot water or of steam. The heat in some mines, where masses of rock have been cooling for thousands of years, causes temperatures above those in which miners can work for more than very short periods. In oil explorations at depths of nearly 20,000 feet, temperatures exceeding the maximum for which well logging machinery is insulated have been encountered.

In all of the present uses of geothermal energy, steam or hot water already present in the earth is put to use, and if it were necessary to confine the utilization of geothermal energy to areas where such subterranean water or steam already exists, the use of that resource would be quite limited. However, it has been suggested that since the temperature of the earth is known to increase as greater depths are reached, it might be possible to construct borings or shafts into which water or some other liquid heat transfer medium could be introduced, and returned to the surface at high temperature for use as a heat source for any purpose. That it would be physically possible to make use of this energy there is no doubt, nor is there doubt that the use



Courtesy Pacific Gas and Electric Company

Figure 19
Geothermal steam power plant at the geysers, Sonoma County, California.

could include distillation of saline water and concurrent generation of marketable electric power. The problems involved in such facilities are largely economic rather than engineering. The principal considerations involved include the location of areas in which the geothermal gradient is high and which are near sources of saline water; determination of heat conductivity of the rocks in those areas; and development of methods for constructing large capacity wells or shafts in rock of high temperature.

This source of energy need not be confined to distillation processes. In areas where the geothermal gradient is high, i.e., where hot beds lie close to the ground surface, it appears possible that this source of energy might be used for the generation of electric power. The outstanding potentiality in its use for demineralization lies in the possibility that a marketable by-product--electrical energy--might be produced to assist in defraying the cost of water.

In 1956, Battelle Memorial Institute undertook a study for the Office of Saline Water, the purpose of which was to survey and evaluate the availability of geothermal energy with particular emphasis on its potential use for the demineralization of saline water. The Battelle study encompassed a survey of available geothermal data, a mathematical analysis of the potential availability of geothermal energy, and an analysis of some of the possible means of utilizing such energy.

The Battelle study^{1/} showed that as a source of high energy of widespread geographic distribution, geothermal energy was not generally practical for saline water conversion. The South Dakota School of Mines Research and Development Association, in 1956, made a concurrent but more specific investigation^{2/} of certain aspects of geothermal energy, including an evaluation of regions of considerable geothermal energy in California, identified as those areas now abounding in hot springs, geysers, steam wells, and mud volcanoes. The investigation was particularly concerned with the problems of the availability of geothermal energy related to the earth's temperature gradient, and the availability of geothermal energy from hot springs and steam wells. The following extract from the Office of Saline Water, entitled "Saline Water Conversion Reports for 1957", briefly covers the findings of the investigation:

"The presently available geothermal data do not indicate that California possesses any areas of unusually high temperature gradients outside the locations of hot springs, steam wells, geysers, and the like. The largest reported gradient is only twice the mean value for the earth's crust. Therefore, no economical utilization of the available geothermal energy from the thermal gradient for a demineralizing process is practicable at this time.

"Hot springs, in effect, afford a 'free hole' for the extraction of geothermal energy. Reported data on fields and temperatures indicate that generally

the potential availability of geothermal energy

1/ Battelle Memorial Institute, "Availability of Geothermal Energy for the Demineralization of Saline Water", Office of Saline Water, Research and Development Progress Report No. 27, July 1959.

2/ South Dakota School of Mines Research and Development Association, "Investigation of the Availability of Geothermal Energy for the Demineralization of Saline Water", Office of Saline Water, Research and Development Progress Report No. 28, July 1959.

the natural flows are too small or the temperature levels too low to utilize them in saline water plants that would be practicable or economical. The cost of fresh water would still be prohibitively high by present standards.

"Steam wells offer the nearest approach to a geothermal source resulting in a practicable demineralization of saline water. The higher temperatures resulting with this natural steam which apparently has been obtained up to 275 psi or so, increases the availability significantly.

"One limitation of such sources is that they are unique and occur only in certain localities, which is also true of hot springs. Thus, one has to consider their feasibility in relation to the source of saline water and area of demand for fresh water.

"Limited and rather old information on steam wells at 'The Geysers' in Sonoma County was used as a basis for estimating that fresh water might be produced for \$1.00 or possibly less per 1,000 gallons in this locality."

Type	operation	Average rating	Installed capacity	Annual power production
Pumping	300,000	1/4 hp	17,000 hp	250 million horse-
Wind Power				
The earliest date when man employed the force of the				

wind to assist him in his tasks is not known. Both the ancient Chinese and Persians used crude wind machines for milling grain, and it is recorded that, in the Seventeenth Century B. C., the Babylonian emperor Hammurabi planned an ambitious irrigation system using windmills for pumping.

In Western Europe and in Russia, windmills were in common use after the middle ages, especially in those regions where fossil fuel and water power resources were negligible, such as Denmark and Holland.

In present-day Russia, where power is required for numerous agricultural communities, a Central Wind Power Institute was established in the 1920-30 decade. The work of

the institute resulted in the construction, in 1931, of a 100-kilowatt electrical generating windmill near Balaclava in the Crimea as well as the construction of numerous small wind-driven generators. Recent estimates give the number of wind power plants in Russia, at about 30,000 units, with an aggregate capacity of approximately 170,000 horsepower.

In the United States, the small farm and ranch windmill was a common necessity in almost all parts of the country until the advent of the stationary internal combustion engine and the rural electrification systems. According to Ayres and Scarlott^{1/}, the types (in 1950) were approximately as follows:

<u>Type</u>	<u>Number in operation</u>	<u>Average rating</u>	<u>Installed capacity</u>	<u>Annual power production</u>
Pumping	300,000	$\frac{1}{4}$ hp	75,000 hp	250 million horsepower-hours
Wind chargers (elect.)	50,000	2 kw	10,000 kw	150 million kilowatt-hours

The total annual power production by wind is about 450 million horsepower-hours, a rather insignificant part of the total United States power production.

During World War II, the possibility of generating electrical power on a large scale from the energy of the wind was studied extensively, and a 1,250-kilowatt wind-driven generator was constructed and operated at Grandpa's Knob near Rutland, Vermont.

^{1/} Ayres, E., and Scarlott, C. A., "Energy Sources; the Wealth of the World", McGraw-Hill Book Company, New York, 1952.

Perhaps the most comprehensive studies of the potentials of wind power in the United States were those accomplished by Percy H. Thomas^{1/} of the Federal Power Commission.

Several types of large units were designed by Thomas, one of which was a two-bladed turbine rated at 7,500 kilowatts at wind velocities of from 23 to 25 miles per hour. Two such units were mounted on the ends of a 235-foot bridge that would swing into the wind on the top of a 475-foot tower.

Another design was a three-bladed turbine rated at 6,500 kilowatts at wind velocities of from 18 to 20 miles per hour, and similarly mounted in panes on towers.

Another proposed design by Thomas was a battery of 10 or more wind-driven turbines located in a power system in a widely dispersed manner so that some units would probably be driven by wind at all times. These wind turbines would operate in coordination with hydroelectric and pumped-storage facilities to achieve some measure of firm power production.

Whatever the diameter of the rotor used, electric windmills are designed to give their maximum power capability at a "rated" wind speed. Energy in a wind of velocity in excess of the rated speed is wasted, and in the case of wind with lower velocity, both the energy input and conversion efficiency of the plant rapidly lessen. Windmills may theoretically extract approximately 60 percent of the energy

^{1/} Thomas, P. N., Federal Power Commission, Washington, D. C., "Electric Power From the Wind", March 1945, "The Wind Power Aerogenerator, Twin-Wheel Type", March 1956, "Aerodynamics of the Wind Turbine", January 1945, "Fitting Wind Power to the Utility Network", February 1954.

in-the-wind. Actually, however, losses in the rotor, in the gearing, and in the electrical system reduce the overall efficiency to less than 40 percent.

The wind rarely blows for any considerable period of time at a constant speed. However, in coastal or mountain areas, locations can be found where it blows more frequently and constantly than in other areas. Extended mountain ranges affect the general flow of air over these barriers and tend to increase wind speeds as the altitude increases.

Therefore, the best sites for wind power are likely to be found at high elevations in mountainous terrain.

At present there appears to be no site in California where wind power can be economically developed and utilized in the California Water Plan.

Utilization of Waste Heat

The amount of heat wasted by industrial processing in California, of possible use in saline water conversion, is not known, even approximately, until recently. To ascertain the approximate quantity of such waste heat, a survey was made of its location, amount, and probable cost.

The objective of this preliminary survey, conducted by Kaiser Engineers under contract to the Department of Water Resources, was to ascertain the location, available quantities, and cost of waste heat energy from various coastal sources

within the State. These sources included industrial concerns, private and public utilities, and municipal, state, and federal installations.

The types of waste heat investigated encompassed the following, namely:

1. Gases, such as the products of combustion and high-temperature effluents from chemical, metallurgical, electric power generation,

municipal refuse, and sewage disposal operations.

2. Liquids, such as the products from refineries, electric power generation, chemical, and preliminary estimates of the cost of plants; sewage disposal,

3. Vapors, such as from electric power, refinery, and municipal refuse and sewage disposal operations, and to the supply of sea water, would be applicable to the cost

4. Solids, such as in the steel, aluminum, ceramic,

and cement industries, and from municipal

Marine Energy

refuse and sewage disposal operations.

Energy exists in the oceans in two different forms--

The survey was limited to the following areas, heat quantities, and heat sources:

water, such as exists off the coast of Southern California, may

1. The Pacific Coastal area, including the lower Sacramento River-San Francisco Bay region,

extending from Napa on the north to the Mexican border on the south, and within 5 miles of the coast line.

2. Those blocks of waste heat, in a given area, capable of producing at least 1 million gallons

per day of potable water employing the vacuum flash evaporation process or techniques of

flash evaporation process or techniques of

flash evaporation process or techniques of

flash evaporation process or techniques of

flash evaporation process or techniques of

flash evaporation process or techniques of

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flash evaporation process or techniques of

required for a 1 million-gallon-per-day plant, depending on the temperature of the waste heat.)

3. Heat sources at temperatures of at least 75° F.
4. Heat sources which are extractable within practical engineering and economic considerations.

The survey disclosed several waste heat sources which would be possible to use as a heat supply for a 1 million-gallon-per-day saline water conversion plant. Preliminary estimates of the cost of use of the waste heat indicated, however, that only the very best sources, from the standpoint of temperature, proximity to an available conversion plant site and to the supply of sea water, would be comparable to the cost of using a conventional heat source.

Marine Energy

Energy exists in the oceans in two different forms--heat and motion. The heat energy existing in the warm surface water, such as exists off the coast of Southern California, may be put to practical use if a heat sink can be provided. This may be done by tapping the cold mass of water lying beneath the surface at depths in the range of 500 to 3,000 feet or deeper. The energy of motion is present in tides and waves, but there appear to be no prospects along the California coast line where either of these sources of energy can be economically harnessed.

Thermal Energy

Historically, the consideration of the extraction of thermal energy from the almost limitless latent energy of the

seas, and its application to the distillation of fresh water from ocean water by the use of small temperature differences, appears to have originated about 80 years ago. Within the past decade, the process has been investigated and improved by an agency of the French Government (Energie des mers) and plants have been considered at Abidjan on the Ivory Coast of French West Africa and at Guadalupe Island in the French West Indies.

Recent contributions to the utilization of thermal energy of the seas date from a demonstration in France, by the engineer Dr. G. Claude, in the 1920's. In this experiment, the possibility of producing mechanical energy from a small temperature difference between two masses of water was demonstrated. Intensified efforts in France, including full-scale testing of components, by Energie des mers, appear to have solved the major technological problems.

The utilization of thermal energy stored in ocean water represents a clever use of the principle that heat can be converted to mechanical energy when two sources of heat of different temperatures are available. Such sources, of almost unlimited size, are to be found in the sea along continental coasts and islands, where the surface water is heated by the sun and is maintained at appreciably higher temperatures than subsurface water. This difference in temperature (20 to 30° F) can be effectively employed to convert heat to mechanical energy.

Little was done with this concept until Dr. Claude constructed a plant in the Bay of Matanzas, Cuba, in 1930,

using a long insulated steel pipe to obtain cold sea water at a depth of about 2,000 feet and warm water from the sea surface. The method operated poorly due to difficulties in laying a pipe to a depth sufficient to obtain enough temperature difference to work with fair efficiency. However, the feasibility of the process was definitely proved.

A number of deep canyons exist off California's coast, which offer potential sources of cold water. An example is Monterey Submarine Canyon in Monterey Bay, which is comparable in maximum depth and cross section to the Grand Canyon of the Colorado River. It heads in the Old Outlet of the Salinas River at Moss Landing. The possibility exists that at Moss Landing either solar heating ponds and/or waste industrial heat could be used to materially increase temperature differentials. A subcanyon of Monterey Canyon is Carmel Canyon, which heads in the mouth of the Carmel River. Considerable depths exist close to shore.

Immediately offshore of Santa Catalina Island, there are two deep submarine basins, namely, the San Pedro Basin to the east and Outer Santa Barbara Channel to the west. Another is the Scripps Submarine Canyon located relatively close to shore at La Jolla, near San Diego. Considerable oceanographic and geologic data concerning this canyon have been made and are available by the Scripps Institution of Oceanography. Typical deep sea water temperature differentials in Southern California coastal waters are shown in Table 18.

Little was done with this concept until Dr. Claude

collected a plant in the Bay of 42-44 fathoms, Cuba, in 1930.

basin is filled during high tide. TABLE 181

TYPICAL DIFFERENCES OF TEMPERATURE BETWEEN SURFACE AND SUBSURFACE SEA WATER

The tide is created, or vice versa. The trapped water is then Southern California Coastal Waters

allowed to flow from the high side to the low side through

Approximate temperature difference	
Water depth, in feet	between surface and given depth, in degrees Fahrenheit

0	0
500	8
March 1949. Surface temperature 57° F	11
1,000	15
2,000	17
3,000	0

0	0
500	20
October 1949. Surface temperature 68° F	22
1,000	26
2,000	28
3,000	0

including heat from nuclear fission. None of these is sufficient to permit the application of this energy source to demineralization of salt water does not appear promising due to the cost of obtaining the cold water and the great volumes of water that must be handled because of the relatively small temperature difference available.

Of the several sources of energy termed "nonconventional", relatively few appear to offer any possibility of future application in this State to water demineralization and transformed into electricity. In principle, the conversion process is analogous to conventional hydroelectric power installations utilizing the energy of falling water. A storage

basin is filled during high tide and is closed by gates when the tide recedes, so that a difference in water level on ebb tide is created, or vice versa. The trapped water is then allowed to flow from the high side to the low side through a hydraulic turbine which may be coupled to a generator to produce electric power. This mode of power generation does not appear to be feasible along the west coast of the United States, except perhaps at Cook's Inlet in Alaska. Table 19 presents typical tidal ranges along the coast of California, all of which are well below the 10-foot minimum generally considered practical and economic for power generation.

Miscellaneous Energy Sources

Other energy sources, less well developed, may eventually assume some importance in supplying energy requirements of the future. These include the fuel cell and various devices for direct conversion of heat to electrical energy, including heat from nuclear fission. None of these is sufficiently advanced at the present time, however, to permit reliable predictions of their potential impact on the energy needs of California.

Summary

Of the several sources of energy termed "nonconventional", relatively few appear to offer any possibility of future application in this State to water demineralization processing and power production. Some are, as yet, in the embryonic stage of investigation and it is therefore impossible

to foresee their possible uses. Energy from marine sources such as the tides and ocean waves may reasonably be excluded from serious consideration in California as large-scale energy sources.

TABLE 19
TYPICAL TIDAL RANGES ALONG THE COAST OF CALIFORNIA^{1/}

Location	Mean range, in feet
San Diego	4.2
Long Beach	3.7
Santa Barbara	3.6
Morro Bay	3.5
San Francisco (Golden Gate)	4.0
San Francisco Bay	
Oakland	4.8
Dumbarton Bridge	6.8
Richmond	4.1
Eureka	4.8

^{1/} From "Tide Tables, West Coast North and South America", United States Department of Commerce, Coast and Geodetic Survey, 1958.

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¹ From "Tide Tables, West Coast North and South America", United States Department of Commerce, Coast and Geodetic Survey, 1958.

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